Deloro Mine Site Cleanup
Tailings Area Rehabilitation Alternatives
Final Report

Prepared for:

ONTARIO MINISTRY OF THE ENVIRONMENT

Prepared by:

CH2MHILL

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Executive Summary

The Deloro Mine/Refinery Site, located in Eastern Ontario, began operation as a gold mine in the 1860s. Over the next 100 years, site activities also included the smelting and refining of a number of other elements including arsenic, silver, and cobalt. Activities associated with the mining, smelting, and refining of metals ceased in the 1950s. These historical activities at the site have resulted in significant environmental impacts to the soil, groundwater, surface water, and sediment quality both onsite and offsite.

Abandonment of the site by its owner(s) forced the Ontario Ministry of the Environment (MOE) to take control of the property in 1979 and to initiate control measures to limit the environmental impact from the site. Remedial initiatives by the MOE have resulted in reductions of arsenic loadings to the Moira River. Arsenic loading to the Moira River has been reduced by more than 80 percent from an annual average of 52.1 kg/day in 1979 to an annual average of less than 10 kg/day since 1983.

To provide further treatment, and to mitigate any unacceptable impacts on human health and the environment, CH2M HILL Canada Limited (CH2M HILL, formerly CH2M Gore & Storrie Limited [CG&S]) was retained by the MOE to develop and implement a comprehensive rehabilitation program focusing on four individual areas of concern at the Deloro Mine Site. These areas included the Mine Area, the Industrial Area, the Tailings Area, and the Young's Creek Area. The purpose of this report is to identify and evaluate remediation alternatives for the Tailings Area and to select a recommended alternative based on the evaluation.

From 1914 to 1960, the Tailings Area was used to dispose of the by-products of the hydrometallurgical process employed at the site. The main component of the tailings is ferric hydroxide (red mud). However, because selective precipitators used in the refining process did not typically offer a high degree of metal separation, metals such as copper, cobalt, nickel, trace heavy metals, and arsenic are also found in the tailings. It is estimated that 90,000 tonnes of dry red mud have been impounded in the Tailings Area.

Previous investigations have indicated that contaminants are released from the Tailings Area by two processes: through leachate movement and by physical transport of fines. Groundwater and pore water sampling in the Tailings Area have shown that contaminants in seepage include arsenic, cobalt, copper, nickel, zinc, cadmium, molybdenum, and silver. The Tailings Area is the single largest source of cobalt contamination on the Deloro Mine Site property and accounts for approximately 71 percent of the total sitewide cobalt loading to the Moira River and Young's Creek. The underlying rationale for remediating this area of the Deloro Mine Site is that by reducing this source of cobalt loading, it is likely that all other less significant metal loads will be similarly reduced.

The evaluation of remediation alternatives was conducted in three stages. The first stage involved the screening of conceptual remediation methods and was designed to identify, early in the evaluation process, the most promising methods for site remediation. In the second stage, comprehensive remediation alternatives were developed by combining the

primary remediation methods that satisfied the first screening process with enhancing protection features. Finally, in the third stage, the comprehensive remediation alternatives were compared to detailed evaluation criteria reflecting technical, cost, natural environment, and social considerations. The comprehensive remediation alternative that was judged to be the most effective and efficient means for remediating the Tailings Area was then recommended.

The first step in the generation of remediation alternatives was the development of conceptual remediation methods. The conceptual remediation methods that were identified for the Tailings Area are as follows:

- Do nothing
- Establish a wetland over the Tailings Area surface
- Cover the surface of the Tailings Area with soil and vegetation
- Establish a permanent water cover over the Tailings Area
- Divert surface runoff away from the Tailings Area
- Collect and treat seepage and groundwater using a conventional or natural treatment system

These methods were then screened to eliminate alternatives that would not be effective, would not comply with regulatory requirements, or that could not satisfy the design closure criteria for the site. The methods that were not rejected were classified as either primary remediation methods or enhancing protective features. Primary remediation methods are methods that have the ability to significantly reduce contaminant loading to the environment. Methods that cannot reduce contaminant loads alone can be combined with the primary remediation alternatives to provide additional protection. The combination of primary remediation methods and enhancing protective features forms the comprehensive remediation alternatives.

The comprehensive remediation alternatives were screened a second time using the exclusionary criteria. This step was completed to ensure that the addition of an enhancing protective feature to a primary remediation method did not undermine that method's ability to mitigate risks to human health and the environment. The following six comprehensive remediation alternatives satisfied the screening criteria a second time:

- Cover the surface of the Tailings Area with soil and vegetation
- Cover the surface of the Tailings Area with soil and vegetation and divert surface runoff away from the Tailings Area
- Cover the surface of the Tailings Area with soil and vegetation and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to a natural treatment system [i.e. wetland and peat bed].)
- Cover the surface of the Tailings Area with soil and vegetation and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to the existing onsite wastewater treatment plant.)
- Cover the surface of the Tailings Area with soil and vegetation, divert surface runoff away from the Tailings Area and collect and treat seepage and groundwater (In this

option, collected seepage and groundwater are directed to a natural treatment system [i.e. wetland and peat bed].)

- Cover the surface of the Tailings Area with soil and vegetation, divert surface runoff away from the Tailings Area and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to the existing onsite wastewater treatment plant.)

The detailed evaluation resulted in the following comprehensive remediation alternative being recommended for the Tailings Area:

- Cover the surface of the Tailings Area with soil and vegetation, divert surface runoff away from the Tailings Area and collect and treat seepage and groundwater from the Tailings Area (In this option, collected seepage and groundwater are directed to the existing onsite wastewater treatment plant.)

The recommended remediation alternative was based on reducing water contact and infiltration through the surface of the Tailings Area, treatment of seepage and groundwater during the vegetation establishment period and after, as required, and reducing the amount of surface run-on from the surrounding environment.

The recommended remediation alternative consists of:

- A soil cover consisting of a layer of silty clay loam in combination with topsoil, sand and compacted clay materials. The topsoil provides the initial rooting medium for the vegetative cover (poplar trees and grasses), while the silty clay loam and sand provide the necessary water storage capacity that will increase the effectiveness of the poplar trees. The compacted clay layer functions as a restricting layer to minimize percolation of water into the underlying limestone cover and tailings (red mud). Based on the findings of the feasibility study (CH2M HILL, May 2002), the construction of a soil cover incorporating a 100- or 150-cm silty clay loam in addition to a 15-cm topsoil layer, a 30-cm sand drainage layer, and a 30-cm compacted clay base is predicted to be sufficient to achieve deep percolation reductions of 83 to 93 percent below existing conditions.
- Installing a collection and pumping system between the Tailings Area and the equalization pond in the Industrial Area will allow for the movement of both seepage and groundwater from the Tailings Area to the equalization/storage basin for treatment at the onsite wastewater treatment plant. Provided that the existing wastewater treatment plant can satisfactorily remove dissolved cobalt from the effluent (the limited existing data suggests that it can), the increase in capital and operation and maintenance costs associated with the installation of a collection and pumping system is considered low compared to the load reduction potential of cobalt to the environment.

Although the use of a soil and vegetation cover is predicted to be effective in reducing the infiltration and deep percolation of water, an interceptor ditch is recommended to achieve a greater level of water inflow reduction. The advantages of an interceptor drain are a reduction of the water flow into the Tailings Area and an expected reduction of the influx of contaminants into the Moira River and Young's Creek. The uncontaminated surface water run-off would likely be diverted to Young's Creek.

Operating, maintenance and monitoring efforts under the recommended alternative will be associated primarily with the Tailings Area cover maintenance (grass mowing in the first

three years, tree replacement and culling, as required, downloading soil moisture data, vegetation sampling and analysis), seepage water collection and pumping system operations and maintenance, and seepage water quality and quantity monitoring. A detailed operations and maintenance plan should be established for the Tailings Area following implementation of the recommended alternative.

Data gaps and issues that should be resolved prior to final design and implementation of the recommended alternative include the following:

- The structural integrity of both the east and west tailings dams will need to be inspected as part of the closure plan development.
- The proposed enhancing environmental protection feature (i.e. to collect and pump seepage and groundwater from the Tailings Area to the equalization pond) is based on an assumption that the existing wastewater treatment plant at the site can remove dissolved cobalt from the effluent, and needs to be confirmed.
- Confirmation of material availability for cover construction and associated costs must be used in optimizing the design.
- Further study is required to determine if the marginally contaminated material from Young's Creek can be used without creating an adverse impact.

The costs associated with the recommended alternative include a capital cost of $5,265,700 and an annual operation and maintenance cost of $139,700. The net present value of the recommended alternative, assuming an effective interest rate of five percent and a planning horizon of 20 years, is $7,094,100. The 20-year period was selected based on the assumption that it is a reasonable period for budgetary planning purposes.

The recommended alternative will be further developed in a subsequent report entitled *Deloro Mine Site Cleanup – Closure Plan for the Tailings Area*. The Closure Plan will be the subject of additional public consultation and stakeholder review in addition to providing supporting documentation for regulatory reviews and applications. The comments will be incorporated into the final rehabilitation strategy and implemented in the construction phase of the project.

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1. Introduction

1.1 Background

Nearly a century of mining and industrial activity has resulted in significant environmental degradation of the Deloro Mine/Refinery site. Tailings and waste zones at the site contain up to 30 percent arsenic. Runoff and seepage from the various waste zones at the site have resulted in arsenic contamination of the Moira River, which flows through the site. Abandonment of this site by its owner(s) forced the Ontario Ministry of the Environment (MOE) to take custody of the property in 1979 and to initiate control measures to limit the environmental impact from the site.

CH2M HILL Canada Limited (CH2M HILL, formerly CH2M Gore & Storrie Limited [CG&S]) was retained by the MOE in April 1997 to develop and implement a comprehensive rehabilitation program for the closure of this former mine site. As part of this comprehensive rehabilitation program, CH2M HILL is developing remediation alternative plans for each of the four areas within the mine site's footprint, as shown in Figure 1-1. The limits of these four areas have been developed based on historical land use and waste disposal practices. The four areas include:

- The Industrial Area, where smelting and refining of the various ores were carried out
- The Tailings Area, where the by-products of the production phase were stored
- The Mine Areas, on both the east and west sides of the Moira River
- The Young's Creek Area, which has been impacted from historical releases from the Tailings Area

Closure plans will be developed for each of these four areas based on the closure objectives identified for the site in the report entitled *Deloro Mine Rehabilitation Project, Development of Closure Criteria, Final Report* (CG&S, October 1998a) and the recommended rehabilitation alternatives developed for each area in the following reports:

- *Deloro Mine Site Cleanup – Industrial Area Rehabilitation Alternatives*
- *Deloro Mine Site Cleanup – Tailings Area Rehabilitation Alternatives*
- *Deloro Mine Site Cleanup – Mine Area Rehabilitation Alternatives*
- *Deloro Mine Site Cleanup – Young's Creek Area Rehabilitation Alternatives*

1.2 Purpose of this Report

The overall objective of the Deloro Mine Site Cleanup is to successfully rehabilitate the mine site to mitigate, within reason, any unacceptable impacts on human health or the environment. As part of this overall objective, several area-specific objectives have been developed. Achieving these objectives, in conjunction with the other area-specific objectives, will aid in the successful rehabilitation of the Deloro Mine Site.

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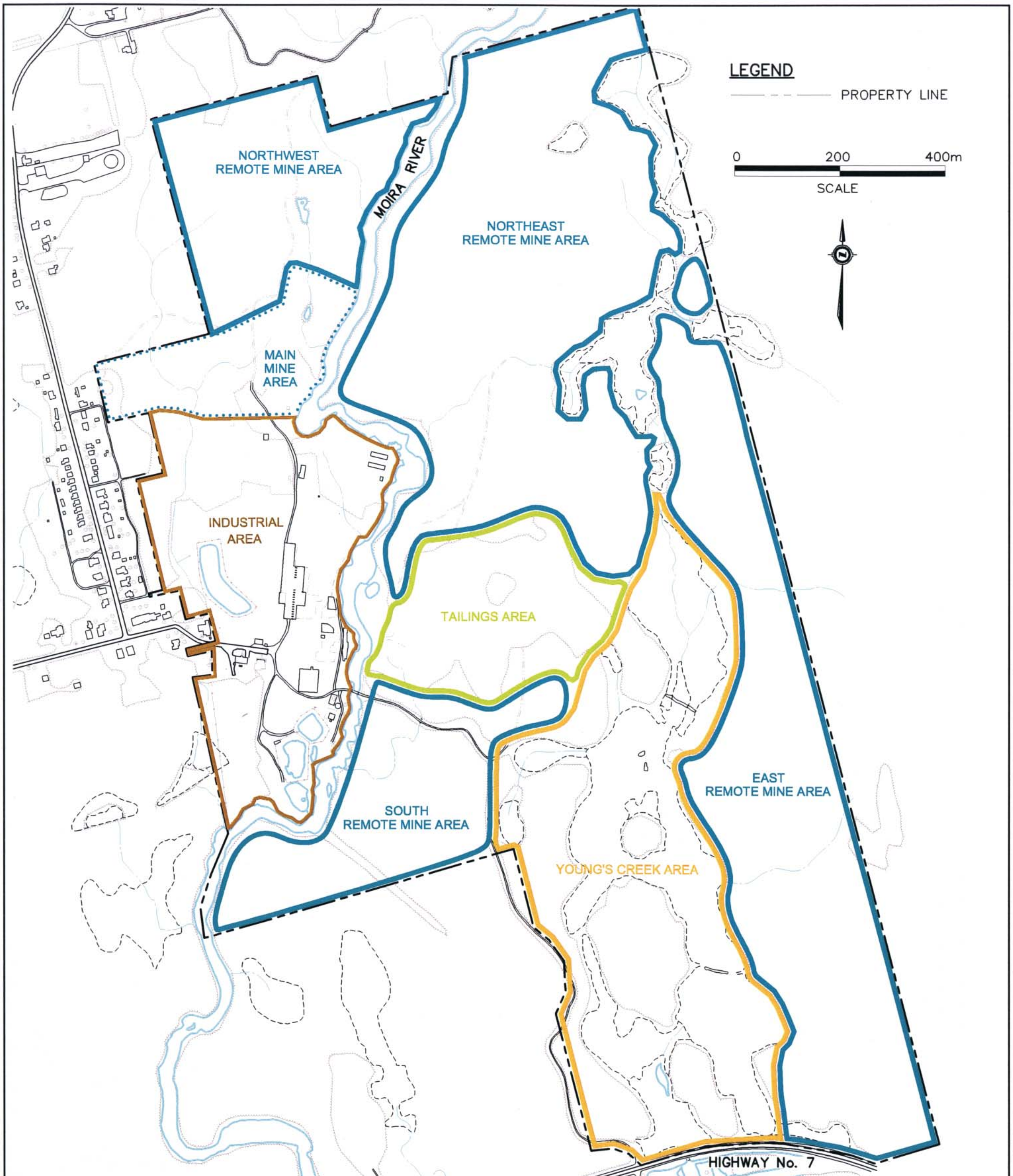

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FIGURE 1-1
DELORO MINE/REFINERY SITE SHOWING THE MINE, INDUSTRIAL, TAILINGS AND YOUNG'S CREEK AREAS
DELORO, ONTARIO

PROJECT No. 119548

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The alternatives reports summarize the previous investigations and reports that have been commissioned for the subject areas. Several alternatives that have been identified in previous reports are evaluated based on their environmental impacts. The criteria used to evaluate the impacts of alternatives reflect all components of the environment, including natural and social environmental impacts, as well as technical and cost considerations. The evaluation approach also recognizes the need to determine and assess "reasonable" remedial alternatives based on existing site information. The identification of remediation alternatives is not intended to be an exhaustive search for all conceivable or experimental remediation solutions that could be attempted. The recommended alternative for each of the four areas will meet the closure criteria established in the report entitled *Deloro Mine Rehabilitation Project, Development of Closure Criteria, Final Report* (CG&S, October 1998a) and will be further developed in subsequent reports outlining closure plans for each of the areas.

1.3 Organization of Report

This report consists of seven sections, including the introduction. Section 2, Background and Problem Definition, describes the history of the site and a brief summary of the results of previous site investigations and studies within the subject area. The existing physical conditions of the subject area including additional background details are described in Section 3, including the nature and volume of the contaminated material. Section 4, Alternatives Evaluation Process, describes the process by which alternatives are generated and the approach to evaluation of the alternatives, as well as the closure objectives that must be met by the rehabilitation alternatives. Additional information pertaining to the detailed evaluation criteria is contained in Appendix A. Section 5, Development and Evaluation of Alternatives, establishes, describes and evaluates rehabilitation methods and alternatives. Section 6 provides the recommended remedial alternatives and cost opinion and identifies any data gaps that should be filled. Details associated with the opinion of cost information are contained in Appendix B. Section 7 lists the references used in the preparation of this report.

2. Background and Problem Definition

This section provides a brief description of the history of the Deloro Mine Site and the Tailings Area. It also clearly defines the problems to be mitigated as part of the recommended remediation alternative. A detailed description of the historical mining activities that have taken place at the Deloro Mine Site since the early 1860s is provided in the report entitled *An Historical Analysis of the Deloro Site* (Commonwealth Historic Resource Management Limited, January 1988).

2.1 Deloro Mine Site

The Deloro site is located in Eastern Ontario along the banks of the Moira River on the eastern boundary of the Village of Deloro (see Figure 2-1, Deloro Mine Site Location). The former refinery/smelter site (Industrial Area) is approximately 25 ha in area and is located adjacent to the west bank of the Moira River. The Tailings Area is located east of the Industrial Area between the East Side of Moira River and the West Side of Young's Creek and is approximately 13 ha in area. The surface area of the mine tailings is approximately 8 ha. The entire property, which includes the Industrial Area, Tailings Area, Mine Area and the onsite portion of Young's Creek, is approximately 202 ha in area. The general boundaries of the Tailings Area are shown in Figure 1-1 in Section 1.

Access to the mine site is via Deloro Road, which is accessed from Highway 7, approximately 4 km east of Marmora. The principal population centres in the area are the Village of Deloro (pop. 180), and the Villages of Marmora (pop. 1,700) and Madoc (pop. 1,400) located approximately 5 km southwest and 10 km east of the mine site, respectively.

The Deloro site began operation as a gold mine in the 1860s and evolved over the next century to mine and refine gold, as well as smelting and refining of a number of other elements including arsenic, silver and cobalt. It was the first plant in the world to produce cobalt commercially and was also a leading producer of stellite, a cobalt-chromium-tungsten alloy. Concentrates from uranium extraction were imported to the site and further processed to extract cobalt. Arsenic-based pesticides were produced from the by-products of smelting operations and continued as a main activity at the site until the market collapsed in the late 1950s.

A century of handling hazardous materials and chemicals has resulted in significant environmental degradation of the Deloro Mine Site. Large quantities of refining slag, mine tailings, calcium arsenate, and arsenical pesticides remained at the site. Fuels, chemicals, and raw materials, such as sulphuric acid, coke, lime, soda ash, caustic soda, liquid chlorine, salt, scrap iron, sodium chlorate, and fuel oil were handled at the site. Radioactive slag and tailings were produced as a result of the re-refining of by-products from uranium refining.

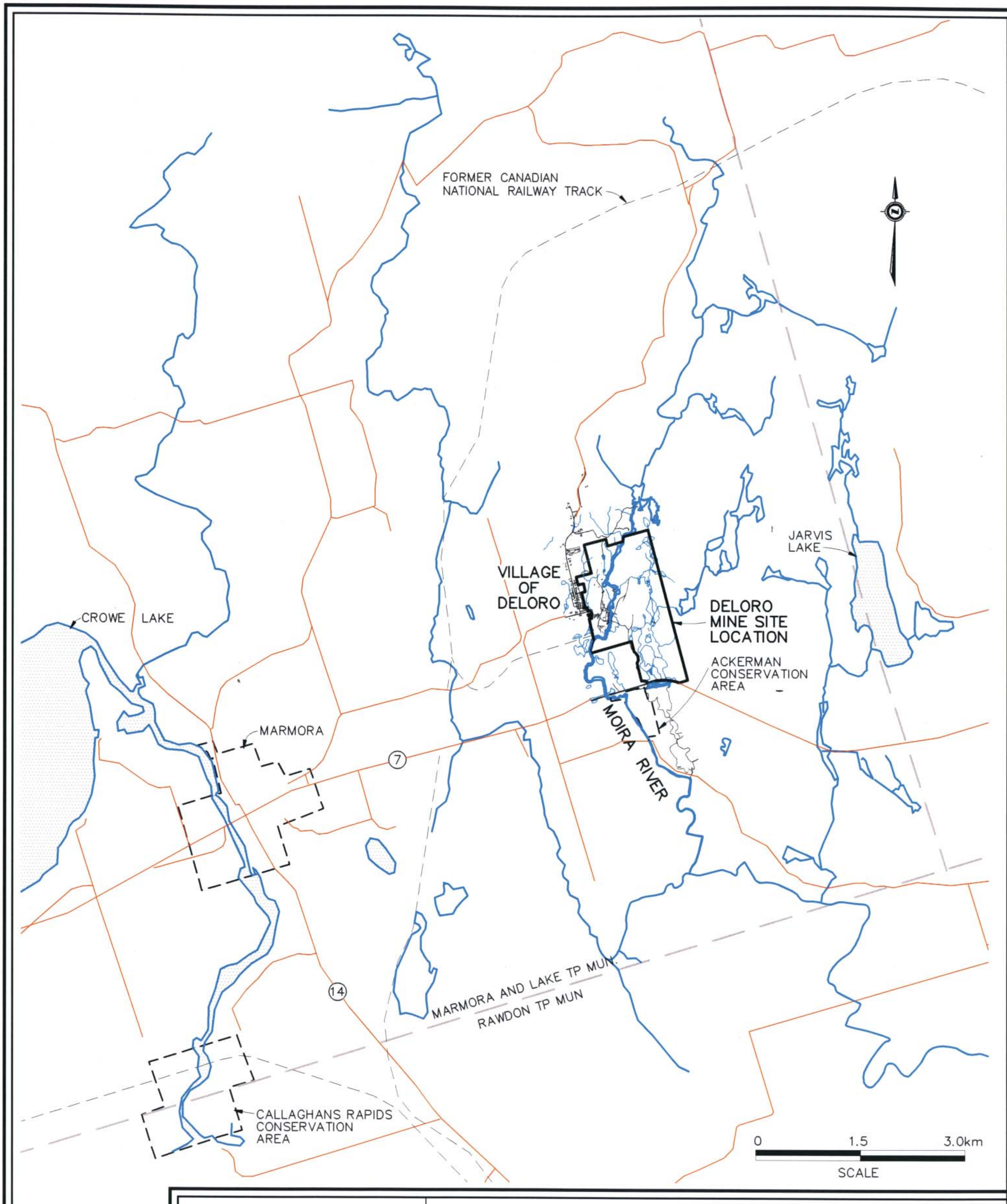

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FIGURE 2-1
DELORO MINE SITE LOCATION

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The Ontario government stepped in to take control of the site in 1979 due to failure of the owner to control environmental releases. The MOE has been in care and control of the site since that time. Several rehabilitation actions have been implemented at the site to date that have significantly reduced releases from the site. In 1979, the annual average loading of arsenic to the Moira River was 52.1 kg/day. Since the arsenic treatment plat was put into operation in 1983, the arsenic loading to the river has been reduced by more than 80 percent, to an annual average of less than 10 kg/day. However, further work is required to reduce releases to acceptable levels and to secure the site for the long term. CH2M HILL was retained in April 1997 to provide consulting engineering and project management services for the Deloro Mine Site Cleanup.

2.2 Tailings Area

The Tailings Area was used from 1914 to 1960 to contain ferric hydroxide (red mud) tailings. The hydroxide tailings were the by-product of the hydrometallurgical process employed at the site. In this process, finely ground ore was digested with acid to extract metals into a solution. Iron was precipitated first, followed by copper, cobalt, and nickel. Precipitated iron was then pumped to the tailings containment area. Sulphuric acid, sodium hypochlorite (bleach), and lime were used in the hydrometallurgical process. A more detailed description of the process used at the Deloro site is provided in Geocon's Phase II Report to the MOE entitled *Chemical Characterization Red Mud Tailings, Deloro, Ontario* (1987).

Since selective precipitators typically did not offer a perfect separation of metals, many of the "contaminating" metals, such as iron, copper, cobalt, nickel, trace heavy metals, arsenic, and sulphates, would likely be found in each precipitation step. Consequently, in view of the processing methods employed at the Deloro site, many of these contaminants of concern were deposited in the tailings containment area.

Another type of contamination found in the Tailings Area is low-level radioactive waste. Tailings containing uranium, a waste product from the cobalt extraction process for manufacturing stellite (cobalt-chromium-tungsten alloy) were deposited in the tailings impoundment. The materials smelted from the late 1920s to 1939 were residues from the refining of radium ores at Port Hope, Ontario. From 1940 to 1946, copper–cobalt–iron alloy residues from Zambia and Katanga were smelted at Deloro. After 1946, cobalt ores from Morocco were treated. The cobalt alloy ore from Katanga is thought to be a potential source of the radioactivity in the Tailings Area (Geocon, 1987). The radioactive material has been delineated as part of the CG&S report entitled *Deloro Mine Rehabilitation Project, Extent and Character of Radioactive Materials, Final Report* (CG&S, June 1999).

2.3 Problem Definition

A plan view of the Tailings Area is shown on Figure 2-2. Based on its location between the Moira River to the west and Young's Creek to the east, it is evident that measures to eliminate offsite contamination generated from the Tailings Area are a major concern. It is likely that the Tailings Area was the primary historical source of contamination in the Young's Creek floodplain sediments (CG&S, October 1998a).

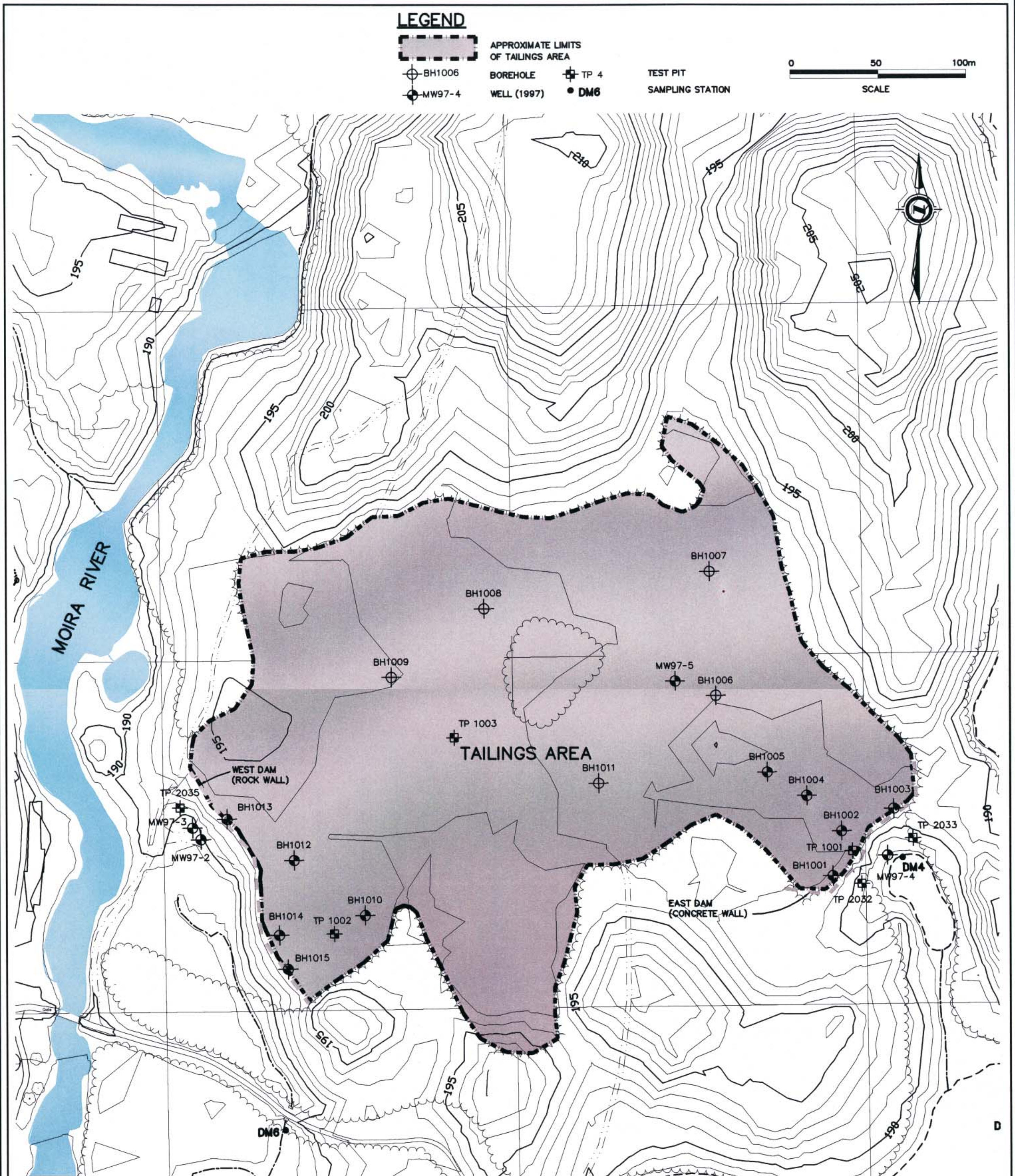

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FIGURE 2-2
DETAILED PLAN VIEW OF TAILINGS AREA

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Previous investigations have indicated that contaminants were released from the Tailings Area by two processes: through leachate movement and by physical transport of fines (CH2M HILL, July 2002). Groundwater and pore water sampling in the Tailings Area indicates that the contaminants in leachate include arsenic, cobalt, copper, nickel, zinc, cadmium, molybdenum, and silver. Radiation fields were also detected underneath the crushed limestone cover of the Tailings Area (CG&S, June 1999). Based on loading calculations of arsenic, cobalt and copper to the Moira River and Young's Creek, it was determined that leachate from both the west and east sides of the Tailings Area contributes significant amounts of cobalt and copper to the Moira River and Young's Creek system on a sitewide basis (CH2M HILL, *Development of a Sitewide Water and Load Balance*, March 2002a).

Although there is evidence that movement of fines has been a problem historically, the current movement of fines through the dam areas on either side of the Tailings Area appears to be insignificant based on their structural stability and the placement of limestone rip rap along the downstream side of the dam faces (CH2M HILL, *Investigation of Mine, Tailings and Young's Creek Areas*, July 2002). The placement of a crushed limestone cover by the MOE in 1987 has also reduced the potential for surface and wind erosion of fine tailings materials (Geocon, 1990). The limestone cover has also been shown to act as a shield against both radioactivity and airborne dust hazards (CG&S, June 1999).

3. Existing Conditions

This section focuses on describing the existing site and environmental conditions within the Tailings Area. It provides descriptions of the physical setting, the natural environment and the social conditions of the Deloro Mine Site and the Tailings Area. This information forms the basis for identifying and evaluating viable remedial alternatives.

3.1 Operations

Current operations with respect to the Tailings Area include:

- Monitoring Moira River and Young's Creek water quality
- Monitoring groundwater quality
- Recording groundwater levels
- Site security

3.2 Physical Setting

This section will outline the physical characteristics that will form a part of the final rehabilitation strategy for the Deloro Mine Site.

3.2.1 Climate

The Deloro area and the surrounding region receives an average yearly precipitation of 889 mm (Environment Canada, 1990). Maximum precipitation usually occurs in the month of September, with approximately 80 to 100 mm of rain. The spring growing season of April, May, and June accounts for about one quarter of the yearly precipitation. The months of September, October, and November account for about one quarter of all precipitation either as rain or snow.

The spring to fall average mean temperature is 16.9°C. The winter mean temperature is -7.4°C. The daily minimum average temperature for January and February is -13.4°C and the daily maximum highs average 25.3°C for the June to August period. The minimum and maximum average temperatures result in a maximum annual range in temperature of approximately 38.7°C. The record high was recorded in the summer of 1988, when temperatures exceeded 40.6°C over a seven-day period. The record low for the area is -40°C. Winds prevail from the west for the months from November to March and from the southwest in the spring and summer months.

3.2.2 Topography

In general, the ground surface at the Deloro site slopes to the south and to the east toward the Moira River. Elevations over the site range from approximately 210 metres above sea level (masl), along the north boundary of the site, to approximately 185 masl, along the banks of the Moira River and in low-lying areas in the south of the property.

The surface topography and drainage have been extensively altered over the more than 100 years of mining, refining, and manufacturing activity on the site.

Figure 3-1 shows the principal topographic features of the Deloro site.

3.2.3 Geologic Setting

The general geologic setting involves the mine site being located at the contact between Precambrian basement rocks and overlying Palaeozoic sedimentary rocks. Bedrock is exposed primarily at the north end of the site and along the Moira River, which passes through the MOE-controlled property. Young's Creek, to the east of the site, is established in a topographic depression flanked by low bedrock scarps and outcrops.

Bedrock Geology

Precambrian metasedimentary and metavolcanic rock forms the bedrock under most of the site except for the western edge of the property, which is underlain by Palaeozoic limestones and shale, and the eastern portion of the property, which is underlain by the Deloro Pluton—a felsic intrusive ranging from granitic to syenitic in composition (Chapman and Putnam, 1984). The syenitic phase of the intrusion is more prevalent on the southern half of the Deloro Pluton. A few skarn lenses occur within 300 m northwest and southwest of the major mine shafts. Granitic phases include syenite, granite, and diorite. The granite is typically pink, massive, medium-grained, and well jointed. The bedrock generally has a northwesterly strike and dips steeply. Joint orientations in the rock trend northeasterly and northwesterly. Frequent weathered fracture planes at 60 to 80 degrees from horizontal were noted in the granite below the cut-off wall along the Moira River.

The surface of the Precambrian bedrock is very irregular and reflects weathering processes during early Palaeozoic times prior to the deposition of the limestone strata that now covers much of the area west of the property. The irregular bedrock surface often protrudes through the overburden forming prominent bedrock knobs over much of the site.

Overburden Geology

The bedrock over much of the site is covered by natural overburden, clay fill, building rubble, tailings, slag, or a mixture of all of these. The natural overburden consists primarily of silty clay with minor amounts of silty sand and peat. These native soils are generally found in areas of low topography. The overburden is generally thin (less than 3 m) but is up to 9 m thick in some areas.

3.2.4 Hydrogeology

The materials present in the Tailings Area (Figure 3-2) are predominantly composed of red mud tailings covered by a layer of crushed limestone. Some lenses of clay and/or black organic material were also observed in some of the boreholes. These lenses were located between the tailings and the bedrock.

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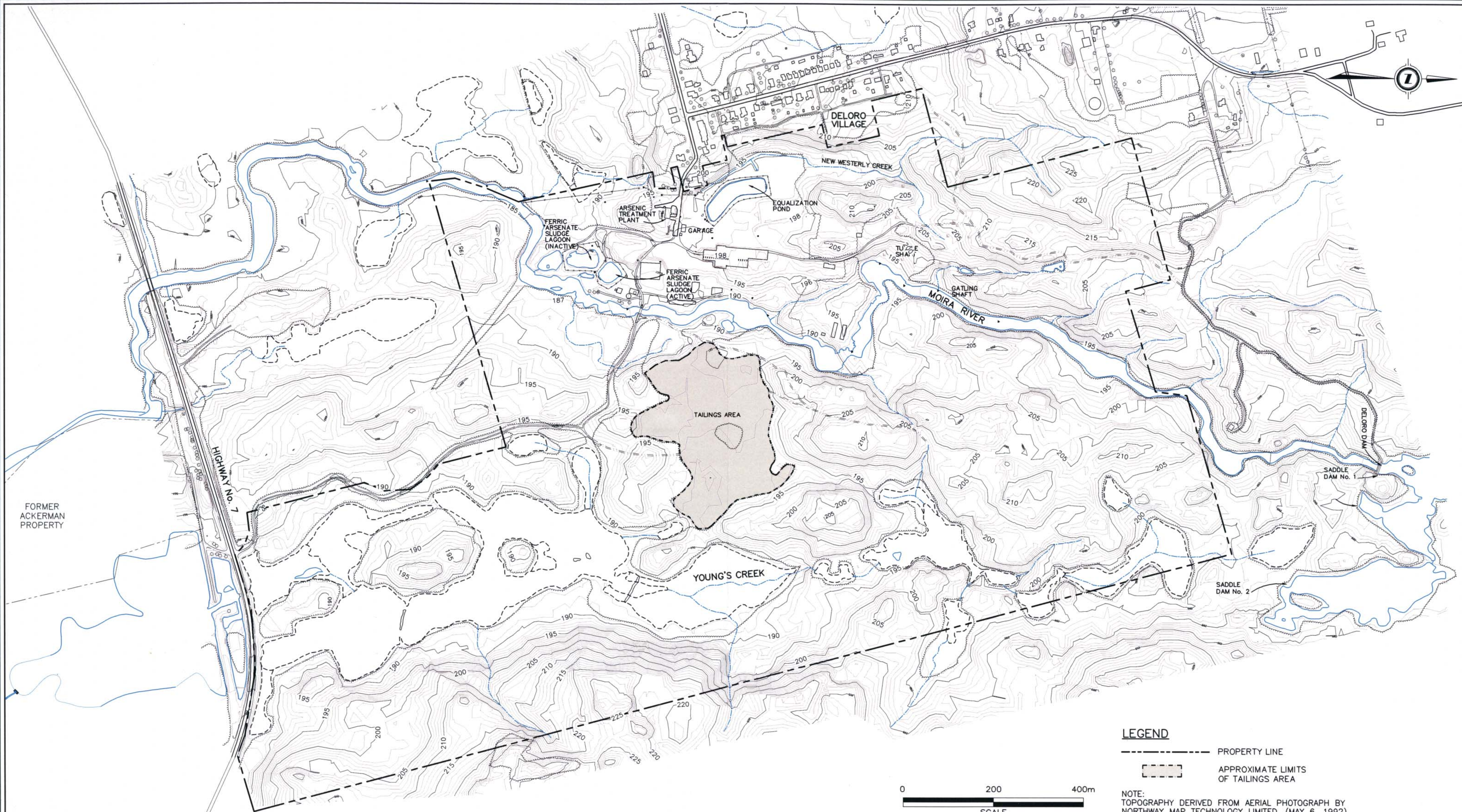

NOTE:
TOPOGRAPHY DERIVED FROM AERIAL PHOTOGRAPH BY NORTHWAY MAP TECHNOLOGY LIMITED. (MAY 6, 1992)

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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3-1
SITE TOPOGRAPHY

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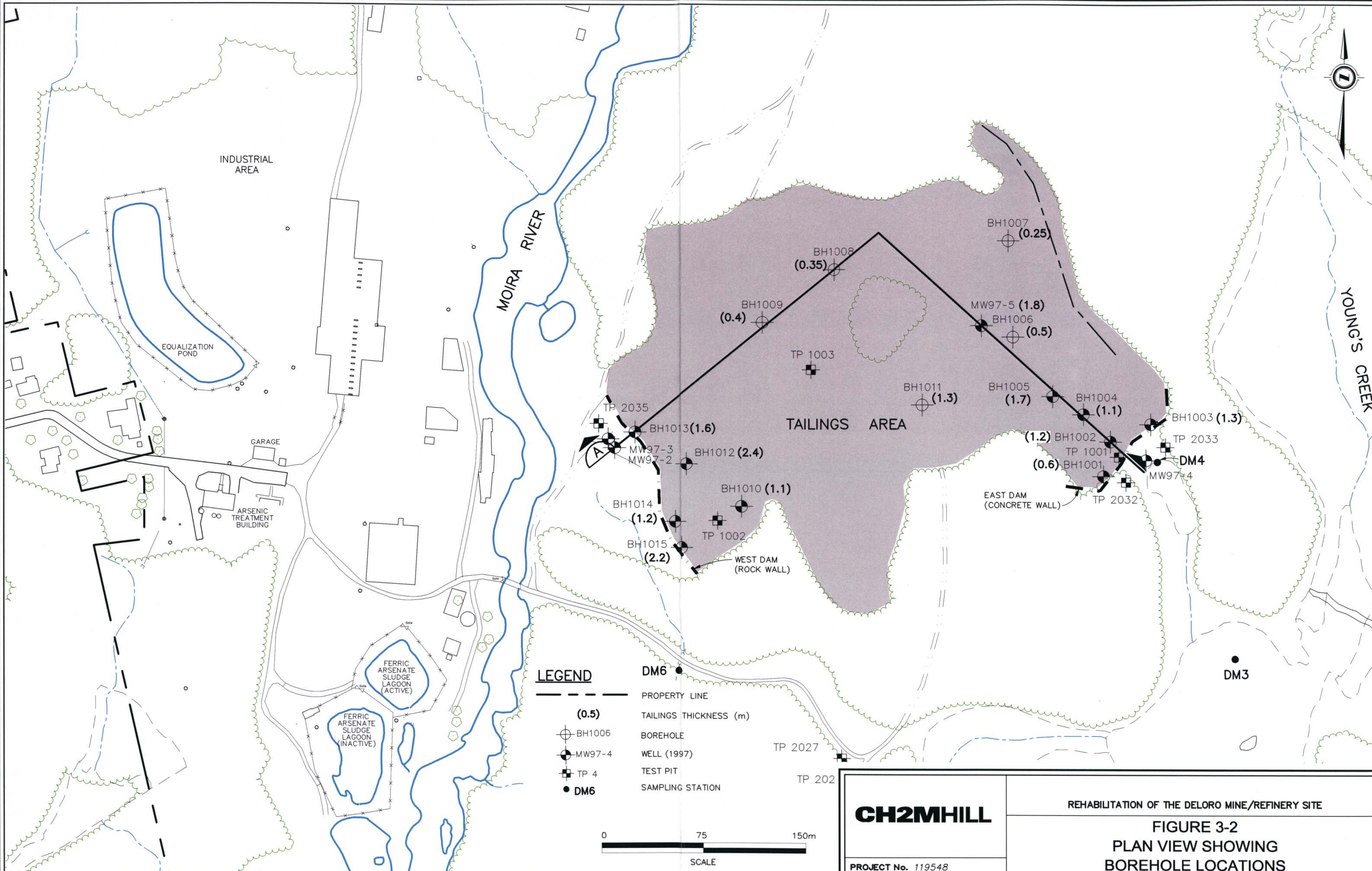

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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3-2
PLAN VIEW SHOWING
BOREHOLE LOCATIONS

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A preliminary hydrogeologic investigation of the Tailings Area was completed in 1997 with the installation and testing of several monitoring wells. One monitoring well was located within the Tailings Area (MW97-5). The screened interval of this well was wholly located within the granite bedrock. The water level recorded in this well (August 12, 1997) was measured at 0.8 metres below ground surface (mbgs). The bedrock begins at a depth of 3.05 mbgs. There was a clay horizon observed in this well between the tailings and the bedrock. The thickness of this layer was estimated at 0.6-m, placing the beginning of this horizon at 2.44 mbgs. The water level in this well is not within the effective screened interval. The water level represents the hydraulic head at this point. The vertical gradient through each of the overburden materials would be needed to calculate the water table elevation. This is impractical in this situation since the composition of each of the overburden materials varies widely over the Tailings Area. The moisture content determined during the tailings investigation (CH2M HILL, July 2002) was 46.9 percent. The tailings are a silt sized material (CH2M HILL, July 2002). The total porosity or moisture content potential for moderately compacted silts (silty loam, silty clay loam and silty clay) is from 44 to 46 percent (Schroeder et al., 1994), suggesting that the red mud tailings are close to this range and indicating that the materials are near saturation. The clay underlying most of the Tailings Area could be impeding the downward migration of infiltrating precipitation and surface water run-on.

The water levels observed in MW97-3 and MW97-4 (August 12, 1997) were both located within the granite bedrock. These wells were located at the base of west dam and east dam, respectively, to assess groundwater conditions and possible migration downgradient of the Tailings Area, where geophysical anomalies suggested the possibility of a leachate plume (Hyd-Eng, August 1997).

The water level observed in MW97-2 was 0.8 mbgs and is located within a clay horizon within the screened interval of the well. This well is also located adjacent to the west dam. This water level is lower than the deepest tailings layer observed in the Tailings Area (see the cross-section presented in Figure 3-3). Monitoring well MW97-3 was located adjacent to MW97-2. The water level in this well was 0.9 mbgs and was located in the bedrock. The water level in this well was located within the effective screened interval of the well.

Where water table levels could be determined from the hydraulic head measurements in the monitoring well (MW97-2, MW97-3, and MW97-4), the water table levels were all measured to be below the deepest observed tailings level. A clay and organic soil mix that was reported as dark grey/dark brown in color with increasing moisture with depth was observed at most of the wells (Figure 3-3). Monitoring well MW97-5 seems to be located in a topographical low. The groundwater may be captured in this low by the low permeability clay/organic mix ($1x10^{-7}$ m/s, CH2M HILL, July 2002) and bedrock ($1x10^{-6}$, CH2M HILL, July 2002). When considering the Tailings Area in three-dimensions, it is possible that the clay/organic mix soil is directing the infiltrating surface and groundwater towards the Moira River or Young's Creek. The latter is considered the more viable option given the different seepage points observed in the area. The bedrock, clay, and tailings topography is undulating and varies greatly from borehole to borehole. From the information presented above, the data would indicate that the primary concern to restricting water from contacting the tailings would be to control the infiltration of water from precipitation and surface water run-on since the groundwater level in the regional area of Deloro appears to be near or below the bedrock/overburden interface. If control of the infiltration and run-on were

achieved, there would still be a subsequent lag time between construction of these measures and the drainage of the tailings due to the low hydraulic driving heads and the relative impermeability of the tailings and underlying strata.

These observations are based on water levels collected during a single event, and therefore subsequent measurements could be used to validate these suppositions.

3.2.5 Hydrology

The Moira River watershed, which includes the Deloro site, is comprised of an area of approximately 2,750 km^2 and flows from this watershed are discharged into the Bay of Quinte on the northern shore of Lake Ontario. Figure 3-4 shows the Moira River watershed area. The Moira River originates in an area of Precambrian rock about 100 km north of the Bay of Quinte. Precambrian rock is exposed at much of the surface in the northern part of the basin. Precambrian rock is overlain by as much as 83 m of Palaeozoic sedimentary rocks consisting mainly of limestone, dolostone, shale, and sandstone in the southern part of the basin. Sand and gravel of glaciofluvial origin, as well as organic deposits, are the primary overburden materials in the northern half of the watershed, while glacial till, glaciofluvial sand and gravel, and glaciolacustrine sand, silt, and clay predominate in the southern portion of the watershed.

The Moira River flows through Wolf, Moira, and Stoco Lakes. The Deloro Mine Site is located approximately 20 km upstream of Moira Lake and is bisected by the Moira River. The majority of the buildings and former processing areas of the mine are located on the west side of the river (i.e. the Industrial Area), while the primary tailings disposal area is to the east of the Moira River and west of Young’s Creek (i.e. the Tailings Area).

Bend Bay, a 21-ha widening of the Moira River, is located approximately 16 km downstream of Deloro and 3 km upstream of Moira Lake. Bend Bay is reported to have a mean water depth of 1 m and a residence time of 0.6 days. Moira Lake is essentially a shallow enlargement of the Moira River and is characterized by two distinct basins. The west basin has a surface area of approximately 200 ha, a mean depth of 4 m, and a maximum depth of 6 m. The east basin has a surface area of 600 ha, a mean depth of 4 m, and a maximum depth of 11 m. The residence time of water in Moira Lake is reported to range from 0.34 years to as long as 4.38 years in the summer (Kilborn, 1983). The west and east basins of Moira Lake are considered to be well mixed during the spring and fall, but transient thermoclines develop during the summer at deeper locations within the two basins, therefore limiting vertical mixing. The Moira River represents the primary flow into and out of Moira Lake.

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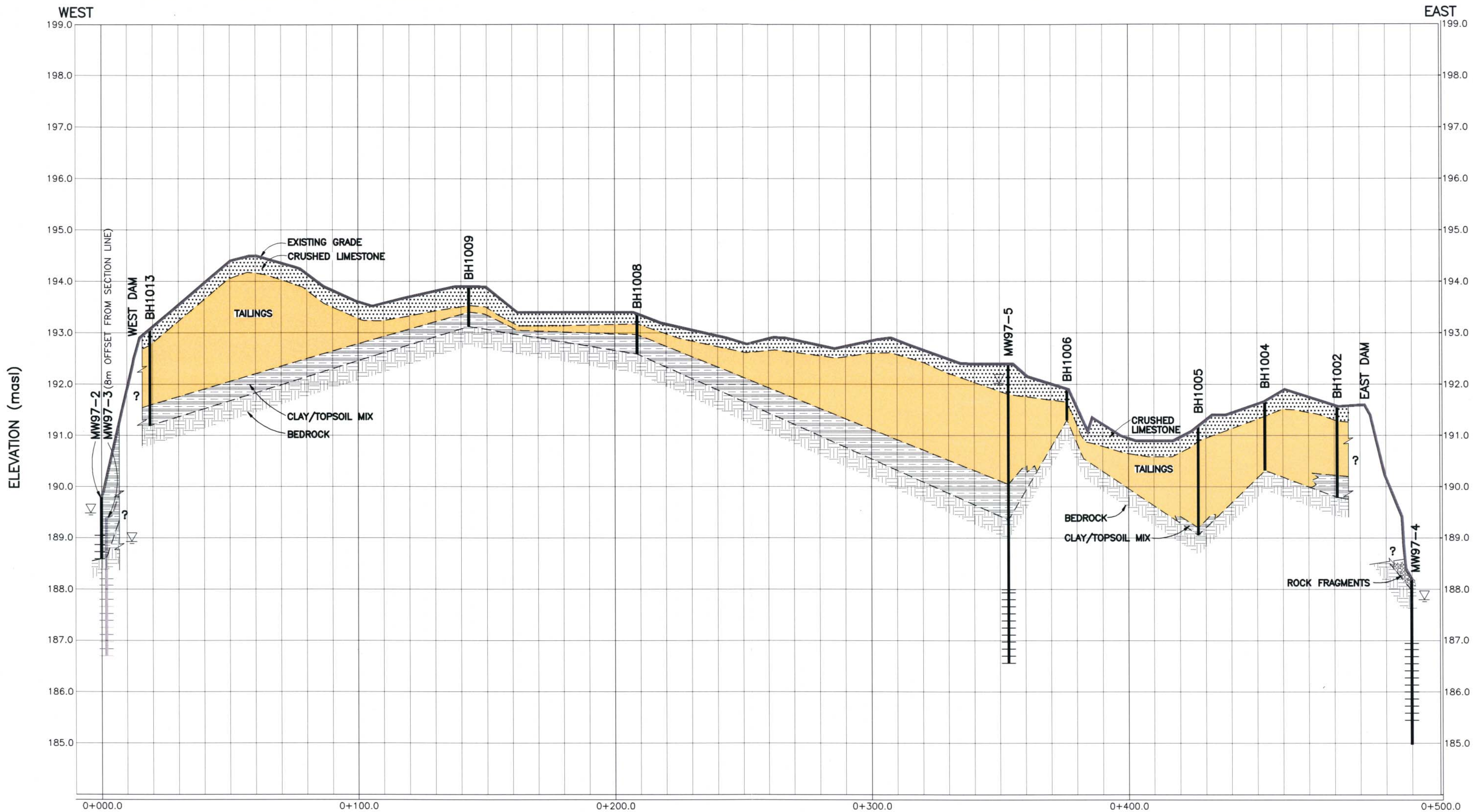

SECTION (A)

HORIZONTAL DISTANCE (m)

LEGEND

▽	GROUNDWATER ELEVATION (JUNE 5, 2002)
masl	METRES ABOVE SEA LEVEL
BH1009	BOREHOLE OR MONITORING WELL IDENTIFICATION
‡	SCREEN PORTION OF MONITORING WELL

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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3-3: CROSS-SECTION SHOWING HYDROGEOLOGY - TAILINGS THICKNESS AND WATER LEVELS

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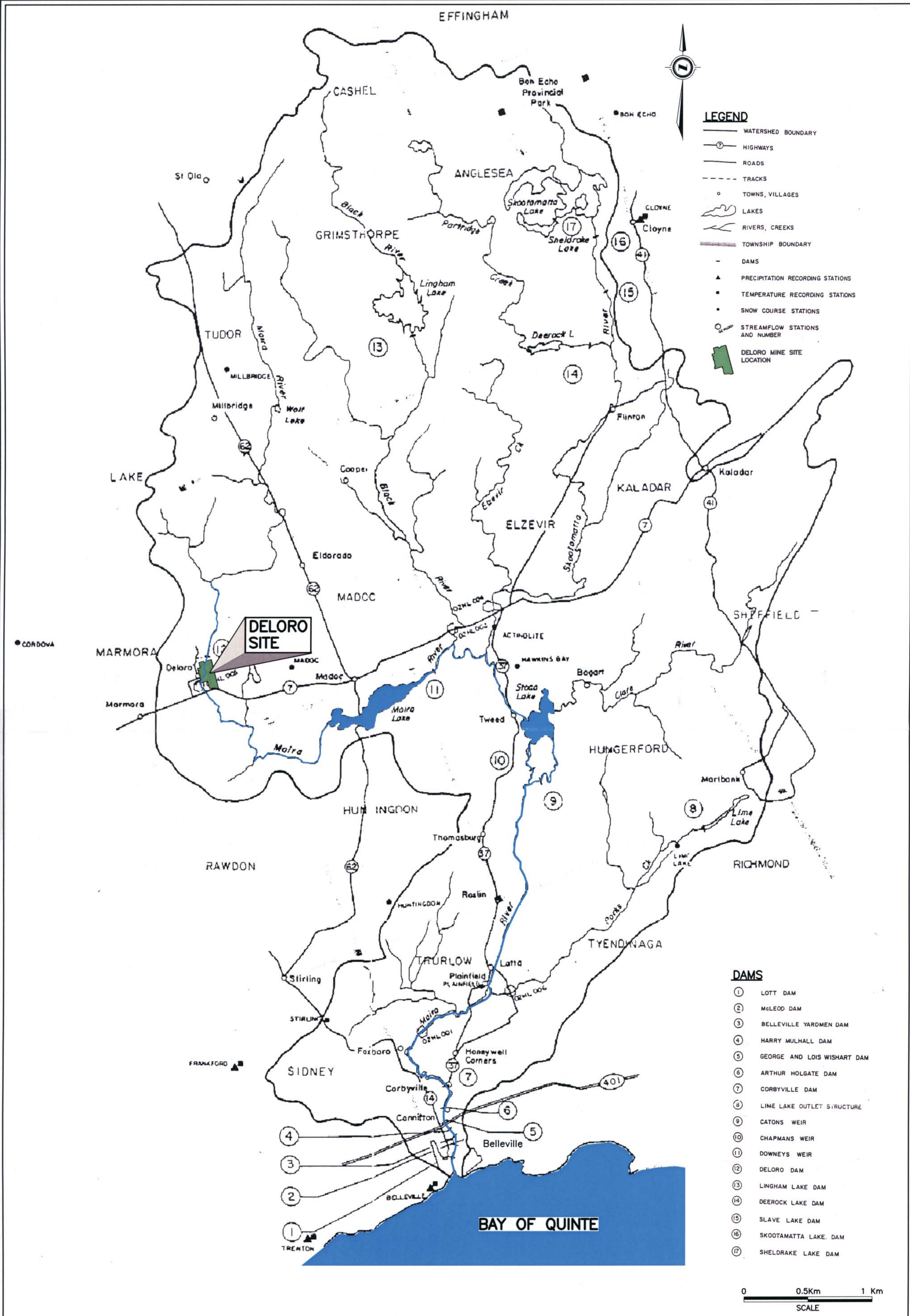

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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3-4
MOIRA RIVER WATERSHED AREA

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Floodplain Mapping

Floodplain mapping was performed for relevant areas (e.g. potentially impacted areas) in both the Moira River and the onsite portion of the Young's Creek watershed sub-catchments (CG&S, November 1998). Floodplain mapping was not completed for the offsite portion of Young's Creek as part of the above noted study. In general it could be expected that similar flood effects would also occur in the offsite portion of the creek with some variations resulting from the steeper gradients in the Young's Creek channel, the influence of the beaver dams, and the influence of the bridge culvert under Highway 7. The floodplain elevations were generated using the hydrologic model BOSS HEC-2™, a water-surface profile computation program. This program is widely used in the field of floodplain management.

In accordance with the Ontario Ministry of Natural Resources guidance documents, the Zone 2 regulatory flood level for the 100-year flood was modelled. Due to the lack of storm flow data for Young's Creek Area, floodplain mapping for this sub-catchment was based on the assumption that the 100-year flow would not exceed 30 percent of the 100-year storm flow for Moira River. Floodplain mapping was performed for the following flows:

- 10 percent of the 100-year flow through Moira River 5.49 m^3/s
- 20 percent of the 100-year flow through Moira River 10.98 m^3/s
- 30 percent of the 100-year flow through Moira River 16.47 m^3/s

It should be noted that several inherent limitations of the model exist due to the lack of flow data as well as the relatively flat nature of the Young's Creek Area, particularly in the onsite portion of the creek. These limitations are explained in more detail in the *Floodplain Mapping*, Final Report (CG&S, November 1998). Flow velocities for the 100-year storm flow are shown in Table 3.1.

TABLE 3.1
FLOW VELOCITIES IN YOUNG'S CREEK WITH A FLOW EQUAL TO 30 PERCENT OF THE 100-YEAR STORM FLOW THROUGH MOIRA RIVER

Cross-Section Number (m)	Channel Mean Flow Velocity (m/s)	Cross-Section Number (m)	Channel Mean Flow Velocity (m/s)
0	0.78	1505	1.7
42	0.52	1520	0.59
55	1.83	1590	2.23
83	1.62	1795	0.42
99	0.3	1920	0.97
135	0.23	1995	2
215	0.16	2055	0.84
565	0.27	2215	0.47
950	0.2	2435	0.19
1265	0.35	2600	1.33
1445	0.96	2620	0.53

The flood risk maps in Figures 3-5 and 3-6 show the 100-year flood boundary and the location of the cross-sections used in the floodplain model. The model predicts that in the event of a 100-year storm, the Tailings Area would remain above the flood waters of both the Moira River and Young's Creek.

The active and inactive ferric arsenate sludge lagoons in the Industrial Area would also remain above the flood waters. However, the third inactive wastewater lagoon (south of the two ferric arsenate lagoons) is predicted to be under flooding waters. The floodplain for the Moira River tends to be narrow, except for the area immediately downstream of the mine site bridge (CG&S, November 1998).

3.3 Natural Environment

An ecological inventory of the Deloro Mine Site property was conducted by CH2M HILL (CG&S, February 1999) during the summer of 1997. The objective of the inventory was to characterize fish, vegetation and wildlife habitat on the site, to assess the habitat characteristics, which contribute to the various assemblages found, and to detect the presence of significant species or groups of species, which could constrain remediation options. The presence or absence of certain organisms was also used to provide preliminary information on whether there are qualitative effects of specific constituents at the site on fish, vegetation and wildlife. Readers are directed to the February 1999 report for specific results.

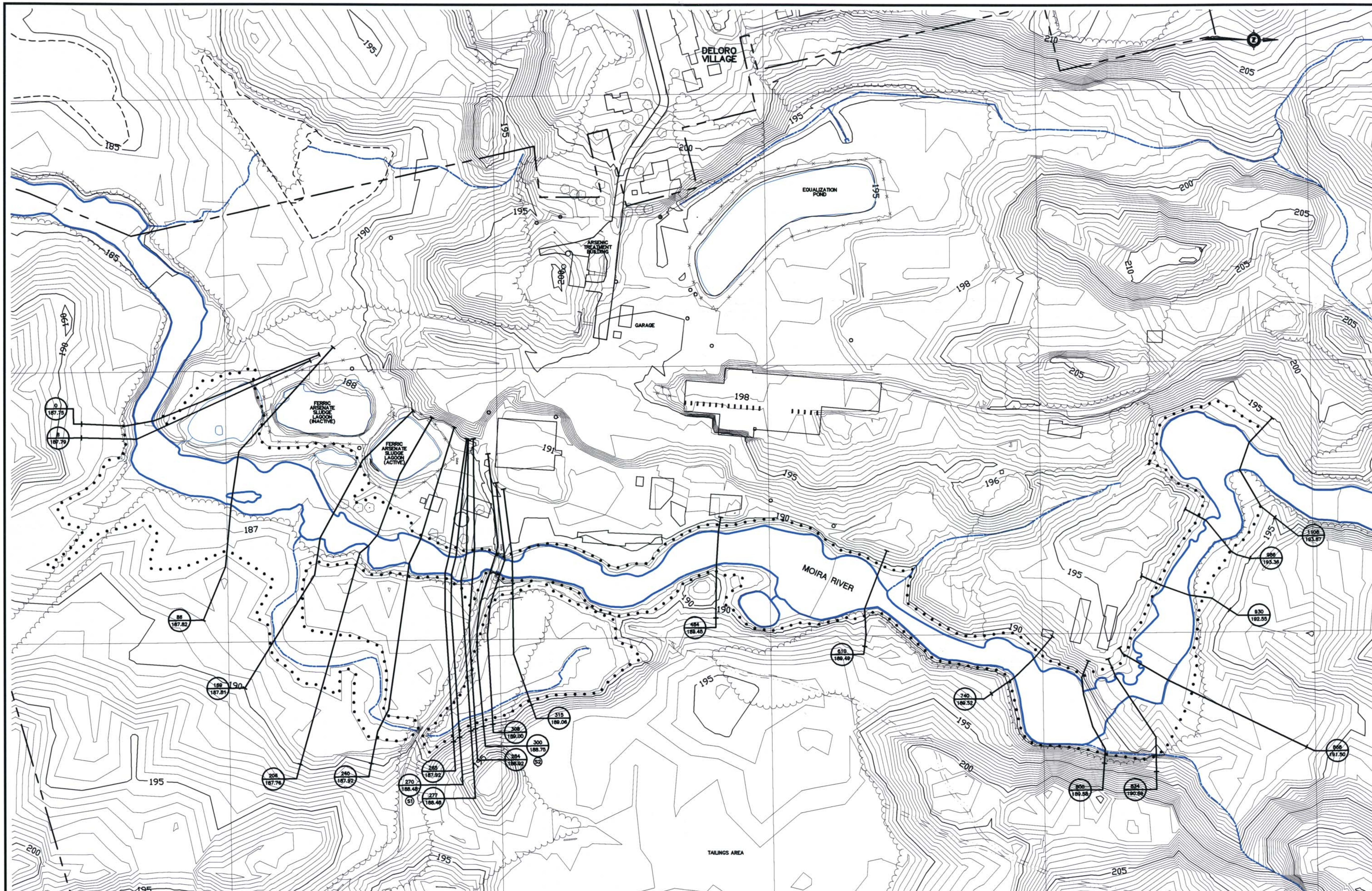
3.3.1 Aquatic Ecology

All watercourses within the vicinity of the Deloro Mine Site sampled for fisheries (which were all within the area of potential contamination associated with past historical mining activities) can be classified as fish habitat. These watercourses support a fishery that is economically important as bait and forage fish for higher trophic levels and as game fish. Nineteen species of fish were captured during the ecological inventory. The species captured were typical of species in the geographic area in warmer reaches of clear flowing streams and marshes. Ages ranged from young of the year to large adult fish, suggesting that spawning is occurring in these reaches. There were no threatened or endangered species of fish found. No evidence of water quality impairment can be derived from fisheries community sampling results (CG&S, February 1999).

3.3.2 Terrestrial Ecology

No rare plant communities were found on the site. Nor were there any rare, threatened or endangered species of plant or animal life found. The composition of plant communities was typical in quality for this location that is intermediate between southern and northern Ontario climatic zones and levels of soil disturbance. Wildlife species were also typical of extensive forests in this area.

Waste arisings on the site may be degrading vegetation in some wetland communities, particularly in the west arm of Young's Creek. However, these conclusions are likely confounded by the effects of other disturbance in this part of Young's Creek, particularly by the removal of beaver dams along the Creek and consequent drying of soils. Plant and animal communities in other areas, whether they contained waste or not, were typical of the habitat in which they were found. The type of vegetation present primarily determined wildlife communities. It was not possible to draw conclusions about the affect of specific constituents on plant communities in upland areas or on wildlife (CG&S, February 1999).



LEGEND

- 86 — CROSS SECTION NUMBER
- 187.82 — 1 : 100 YEAR FLOOD ELEVATION
- (S1) — STRUCTURE IDENTIFICATION
- • • • • • • • • • 1 : 100 YEAR FLOOD BOUNDARY

SCALE: 0 — 25 — 50m

NOTES:

1. THIS DRAWING IS OF A CONFIDENTIAL NATURE AND SHALL NOT BE REPRODUCED IN ANY MANNER, NOR USED FOR ANY PURPOSE WHATSOEVER EXCEPT BY WRITTEN PERMISSION OF CH2M HILL CANADA LIMITED.
2. THIS DRAWING IS NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED. DESTROY ALL DRAWINGS BEARING EARLIER DATE AND / OR REVISION NUMBER

DES.	
DRN.	DJF
CHK.	

REF DWG NO	NO	DATE	REVISION	BY	CHK'D	APP'D
		27/MAY/03		DJF		

Ministry of the Environment
Ontario

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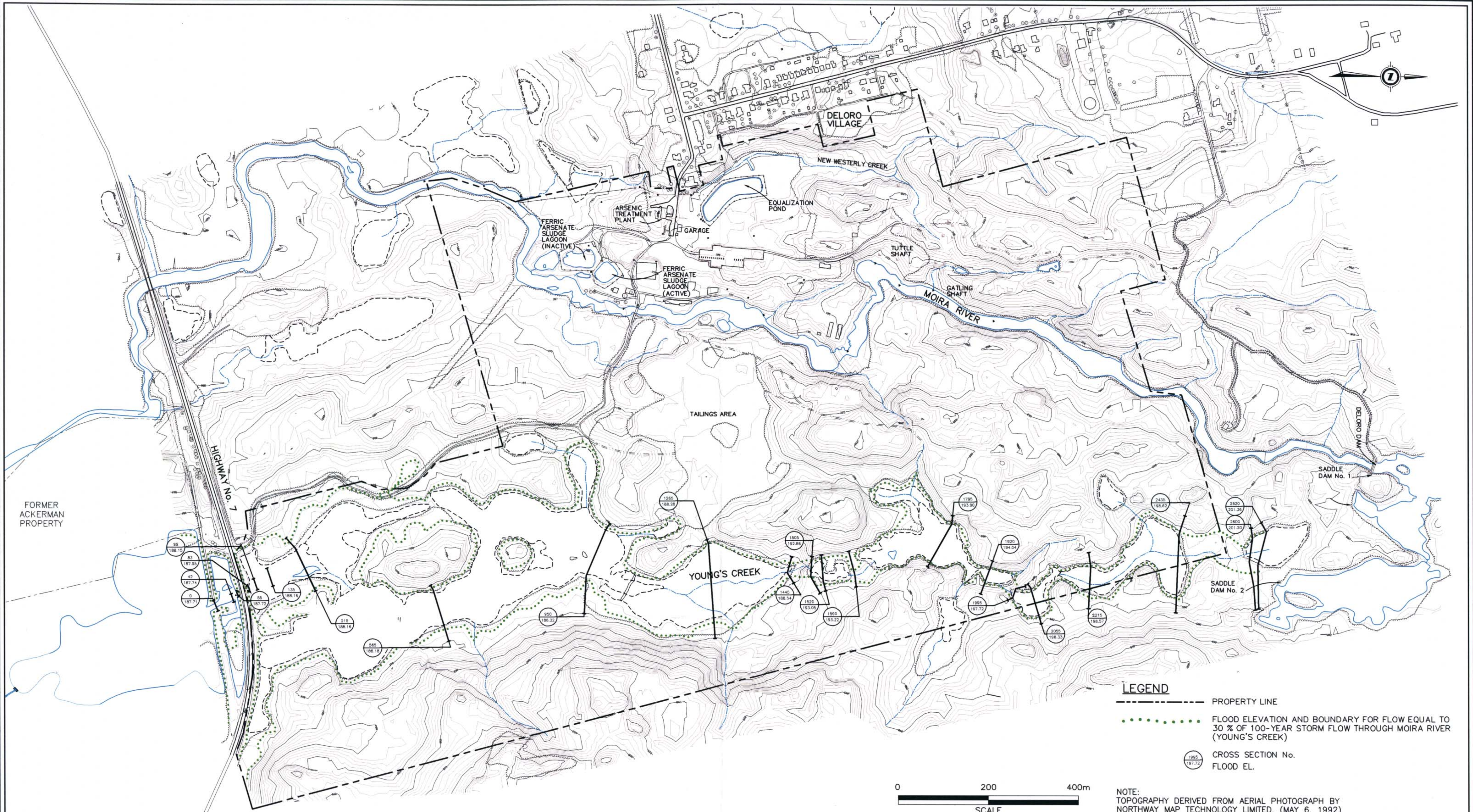
REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3–5
FLOOD RISK MAP – MOIRA RIVER

DWG NO
SCALE AS SHOWN
SHEET
OF
REV NO

27/JUNE/2003



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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 3-6
FLOOD RISK MAP
YOUNG'S CREEK

PROJECT No. 119548

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Succession in remediated areas will likely proceed slowly in areas where bedrock is close to the surface, as these areas are nutrient- and moisture-deficient. Succession will likely proceed from early successional communities, such as the one found on the tailings cap, through more advanced successional communities to communities that will ultimately be determined by soil conditions, microclimate and surrounding vegetation. It is recommended that native species currently found in soils over bedrock be used for restoration after remediation, as they are well adapted to these conditions.

3.4 Social Conditions

The Tailings Area is part of the larger Moira River watershed; therefore, any impacts attributed to the Tailings Area could consequently impact the social conditions associated with the Moira River. The Tailings Area is located in the old Township of Marmora and Lake[1], between and immediately adjacent to the Moira River and Young's Creek (Figure 1-1). Young's Creek originates in an area of low topography just south and east of the Deloro Dam and Reservoir and flows in a southerly direction before discharging into the Moira River approximately two kilometres south of Highway 7. The Moira River continues easterly into Moira Lake and, from there, flows southerly to the Bay of Quinte.

The land use along the Moira River within the old Township of Marmora and Lake is primarily zoned as environmentally protected areas, with the surrounding land uses primarily zoned as rural. Development along the Moira River and Young's Creek, from Deloro to Moira Lake, is generally sparse. The Moira River Conservation Authority indicated that 11 houses and three farms are adjacent to this section of the Moira River. Nine of these houses are located at the mouth of the river at Moira Lake.

Use of the Moira River, Young's Creek and Moira Lake within the old Township is primarily recreational, consisting of fishing and boating. Potable water within the Township is obtained primarily via private wells. Discussions with the Moira Lake Property Owners' Association also indicated that most landowners in the area are aware of the concerns associated with water quality, and consequently there are no potable uses of river or lake water. There appears to be very little agricultural land near the Moira River, Young's Creek or Moira Lake. Consequently, use of the river or lake for agricultural purposes is also unlikely. Readers are directed to the *Survey of Moira River Water Use – Update*, Final Technical Memorandum (CG&S, October 1998c) for further details.

3.5 Physical Conditions in the Tailings Area

The Tailings Area is one of the two disposal sites where red precipitate was pumped as a waste slurry from a hydrometallurgical plant that operated from 1914–1961 (Geocon, 1987). During the ore refining process, ferric hydroxide–ferric arsenate (red mud) tailings were pumped on the east side of the Moira River into a lowland area existing as a process of natural settling/dewatering and solution runoff until 1961, when the entire plant was shut down (Geocon, 1987). Previous estimates by the former owners of the property (Deloro

[1] The recent amalgamation has changed the jurisdiction this township falls under.

Stellite Limited) indicate that approximately 90,000 tonnes of dry red mud has been impounded in the containment area that lies in a knoll of Precambrian rock (Geocon, 1986).

The Tailings Area is about 370 m long by 220 m wide, with its long axis oriented in an east–west direction and covering an area of about 8 ha (Geocon, 1986). The east and west ends of the Tailings Area are both dammed. The west dam comprises primarily hand-placed rock and measures about 140 m long and approximately 4 m high, while the east dam consists primarily of a concrete wall that measures 115 m long and nearly 4 m high. Between these dams, the surface of the red mud is close to the crest elevation and there has been some loss of red mud onto the downstream side of the dams (Geocon, 1986). The perimeter of the containment area lies in a geodetic elevation of approximately 192 m (Geocon, 1990). Geocon (1987) estimated that the entire catchment area, which flows into the red mud surface (including the red mud surface itself), was approximately 16.1 ha.

Since 1987, a layer of crushed limestone has covered the Tailings Area. This limestone cover was placed by the MOE to eliminate the transfer offsite of tailings material by wind and water erosion and to increase the pH of the surface runoff water from acidic to slightly alkaline (Geocon, 1990). The limestone cap is pervious and is designed to allow for water infiltration to occur beneath the cap, allowing for chemical neutralization of acidic runoff and seepage waters from the Tailings Area.

Prior to the placement of the limestone cap, the red mud surface was sloped from west to east at an average grade of about one percent (Geocon, 1986). After the limestone cap was placed, a similar grading pattern was followed in an effort to place a uniform coverage of 0.5 m across the surface (Geocon, 1990). A detailed description of the grading pattern of the limestone cap, cross-sections, and a record of construction is provided in the Geocon Lavalin *As-Built Report, Site Reclamation Phase III-Red Mud Containment Area* (1990). A cross-section of the east and west dams and the catchbasins installed downstream of the dams is also included in the as-built report.

Currently, stratigraphy data from 15 borehole samples taken by Steffen, Robertson & Kirsten (Canada) Limited (SRK) in 1997 indicate that the depth of crushed limestone cover varies from approximately 0.15 to 0.40 m (CH2M HILL, July 2002). Beneath this limestone cover, the thickness of the red mud is variable depending on the location. The thickness of the red mud encountered in boreholes and test pits near the east dam concrete wall varied between 1.2 and 3.6 m. The thickness of red mud in boreholes and test pits near the west dam rock wall varied between 2.7 and 3.2 m. Based on liquid and plastic limits, the red mud would be classified, according to the *Unified Soil Classification System*, as an organic clay or compressible organic silt (Geocon, 1987). Figure 3-3 presents a cross-section of the Tailings Area impoundment.

On the basis of results from soil mechanics classification tests and site observations, it is inferred that the hydraulic conductivity of the deposit is less than 10^{-6} cm/sec (Geocon, 1987).

3.6 Contaminants in the Tailings Area

Witteck Development Inc. (1986) conducted a metallurgical study of the red mud tailings to determine the composition and chemical characteristics of the red mud as originally

discharged in the Tailings Area (i.e. prior to placement of the crushed limestone cover). The study revealed that the red mud solids are comprised of the elements shown in Table 3.2.

TABLE 3.2
APPROXIMATE ANALYSIS OF RED MUD (WITTECK, 1986)

Element	Percentage	Element	Percentage
As	4.29	Bi	0.030
Co	0.19	Ni	0.21
Fe	11.10	Ca[1]	14.8
Cu	0.59	SO_4[1]	38.4
Pb	0.019		

[1]Chemical Characterization Red Mud Tailings (Geocon, 1987)

These findings indicate that the predominant elements within the tailings are sulphate, calcium, and iron residues, in association with heavy metals. Witteck (1986) also found that the pH of the red mud pore water was low, with an indication that acidity was increasing over time. Increased acidity is known to increase the solubility of arsenic and other heavy metals in pore water and could potentially become a serious problem if leakage occurs to the surrounding water system (Geocon, 1987). Concerns relating to increased acidification and high concentrations of arsenic and metal ions in runoff essentially diminished following placement of the crushed limestone cover in 1987. There is no conclusive evidence to suggest the limestone impacted the seepage pH; however, the pH of surface runoff water has changed from acidic to slightly alkaline (Geocon, 1990). The limestone cover has also provided a stable surface for light vehicular travel.

SRK (CH2M HILL, July 2002) examined the heavy metal content of the tailings solids beneath the limestone cover. This investigation consisted of borehole samples taken throughout the Tailings Area, as shown on Figure 3-2. It was found that arsenic, copper, nickel, and cobalt were significantly elevated above surface residential/parkland soil criteria for use in a potable groundwater situation. Results from these borehole samples are summarized in Table 3.3.

TABLE 3.3
CONTAMINANT CONCENTRATIONS IN RED, BROWN, AND YELLOW ORANGE/CREAM TAILINGS AS DETERMINED BY 1997 BOREHOLE SAMPLES TAKEN BY SRK

Chemical Parameter	Ranges in Concentrations (mg/kg)	Table A Soil Criteria Residential/Parkland[1] (mg/kg)
Arsenic	16,500 to 36,300	20
Copper	498 to 25,400	225
Nickel	211 to 4,450	150
Cobalt	180 to 1,130	40

[1]Guideline for Use at Contaminated Sites in Ontario (MOE, 1997)

These results indicate that arsenic and copper are the primary contaminants within the tailings solids. The study showed evidence that the areas surrounding the tailings materials were also contaminated by heavy metals. Organic material underlying the tailings contained

arsenic, cobalt, copper, and nickel approaching or exceeding criteria. Arsenic and copper levels in the silt and fine sand samples beneath the tailings and above the bedrock layer also exceeded criteria (CH2M HILL, July 2002).

3.6.1 Pore Water Contamination in the Tailings Area

Earlier investigations have established that offsite contamination occurs primarily through water movement through tailings materials, based on the elevated levels of contamination in the tailings solids and in the surrounding area (Geocon, 1986; 1987).

The most recent pore water sampling investigations provide an indication of current water quality conditions within the tailings impoundment. In 1997, SRK conducted pore water sampling at locations along the east dam (97-TL-TP-1001), west dam (97-TL-TP-1002), and at the centre of the Tailings Area (97-TL-TP-1003), as shown on Figure 3-2. The results of these sampling investigations are shown in Table 3.4. The Provincial Water Quality Objectives (PWQO) are presented in this table for comparison.

Generally, metal concentrations in pore water were highest in the centre of the Tailings Area and lowest at the east dam. Concentrations of arsenic, copper, nickel, and cobalt were higher than the PWQO, with the exception of arsenic in the centre of the Tailings Area, which was below the detection limit.

As shown in Table 3.4, the highest pore water concentrations of copper and nickel were found in stations along the west dam and the centre of the Tailings Area, where the corresponding pHs are 4.25 and 5.00, respectively. Given the magnitude of contamination in the tailings solids, pore water appears to be significantly less impacted than might be expected. However, concentrations for cobalt, copper, nickel, and zinc are considerably above the PWQO. These parameters need to be addressed by the recommended remediation alternative.

TABLE 3.4
METAL CONCENTRATIONS IN TAILINGS AREA PORE WATER[1]

Parameter	Units	Table A Potable Groundwater Criteria	PWQO	97-TL-TP –1001 East Dam	97-TL-TP –1002 West Dam	97-TL-TP –1003 Centre
Collected Volume	mL			100	50	250
pH	s.u.			6.59	4.25	5.00
Redox	mV			415	474	479
Conductivity	uS/cm			1,759	1,806	1,812
Acidity	mg/L $CaCO_3$			7.5	insufficient sample	157.0
Alkalinity	mg/L $CaCO_3$			8.8	insufficient sample	2.3
Sulphate	mg/L			1,450	1,330	1450
Total Metals						
Aluminum	mg/L	-	(0.075)	<0.2	2.4	0.7
Antimony	mg/L	0.006	(0.02)	**<0.2**	**<0.2**	**<0.2**
Arsenic	mg/L	0.025	(0.005)	**0.8**	**0.3**	<0.2
Barium	mg/L	1	-	<0.01	0.01	<0.01
Beryllium	mg/L	0.004	0.011	**<0.005**	**<0.005**	**<0.005**

TABLE 3.4
METAL CONCENTRATIONS IN TAILINGS AREA PORE WATER[1]

Parameter	Units	Table A Potable Groundwater Criteria	PWQO	97-TL-TP –1001 East Dam	97-TL-TP –1002 West Dam	97-TL-TP –1003 Centre
Bismuth	mg/L	-	-	<0.1	<0.1	<0.1
Boron	mg/L	5	(0.2)	0.1	0.1	0.2
Cadmium	mg/L	0.005	(0.0001)	**<0.01**	**<0.01**	**<0.01**
Calcium	mg/L	-	-	517	531	541
Chromium	mg/L	0.050	0.1	**<0.01**	**<0.01**	**<0.01**
Cobalt	mg/L	0.1	0.0009	**13.1**	**5.32**	**30.9**
Copper	mg/L	0.023	(0.001)	**0.12**	**75.4**	**76.9**
Iron	mg/L	-	0.3	0.06	0.1	0.13
Lead	mg/L	0.01	(0.001)	**<0.05**	**<0.05**	**<0.05**
Lithium	mg/L	-	-	0.01	0.01	<0.01
Magnesium	mg/L	-	-	12	15.1	18.9
Manganese	mg/L	-	-	0.373	0.122	0.225
Molybdenum	mg/L	7.3	0.04	0.41	<0.03	<0.03
Nickel	mg/L	0.1	0.025	**6.75**	**10.3**	**15.4**
Phosphorus	mg/L	-	0.03	<0.3	see below	see below
Potassium	mg/L	-	-	11	3	8
Selenium	mg/L	0.01	0.1	**<0.2**	**<0.2**	**<0.2**
Silicon	mg/L	-	-	20.8	42.6	50.2
Silver	mg/L	0.0012	0.0001	**<0.01**	**0.02**	**0.02**
Sodium	mg/L	-	-	19	7	6
Strontium	mg/L	-	-	0.708	1.78	1.47
Thallium	mg/L	0.002	(0.0003)	**<0.1**	**<0.1**	**<0.1**
Tin	mg/L	-	-	<0.03	<0.03	<0.03
Titanium	mg/L	-	-	<0.01	<0.01	<0.01
Vanadium	mg/L	0.2	(0.007)	<0.03	<0.03	<0.03
Zinc	mg/L	1.1	(0.02)	0.097	**0.57**	**2.3**

Bolded values exceed potable groundwater criteria for all use categories listed in the Guideline for Use at Contaminated Sites in Ontario, 1997, Table A
PWQO = Provincial Water Quality Objectives for protection of aquatic life
( ) = Interim Provincial Water Quality Objectives
[1] Deloro Mine Rehabilitation Project, Investigation of Mine, Tailings and Young's Creek Areas, Final Report (CH2M HILL, July 2002).
Laboratory Comment: Total phosphorus was not analyzed due to interference from copper.

3.6.2 Geochemical Behaviour of Tailings Solids

The solubility of metals within the tailings solids under aerobic and reducing conditions and under flooded conditions was investigated by SRK in 1997 and reported in CH2M HILL (July 2002). Leach tests were conducted for each condition and metal concentrations in the leachates monitored. This leaching behaviour is an important criteria to consider when evaluating the potential effectiveness of closure alternatives.

In summary, concentrations of nickel, cobalt, copper, and arsenic will exceed the PWQO under aerobic, reducing and flooded conditions. The concentration of zinc will likely exceed the PWQO under reducing and flooded conditions. Nickel, cobalt, copper, and zinc levels increase by one to three orders of magnitude under reducing and flooded conditions compared to aerobic conditions. Arsenic levels are similar under aerobic and reducing conditions; however, levels gradually increase under flooded conditions. Test results are summarized in Table 3.5.

TABLE 3.5
SUMMARY OF LEACHATE TEST RESULTS (CH2M HILL, JULY 2002)

	Cycle Number				
	1	**3**	**5**	**6**	**10**
Arsenic Concentrations (mg/L)					
Aerobic	0.5	0.9		0.778	
Reducing	0.7	0.649		0.799	
Flooded column, leachate	0.2		1.39		2.1
Flooded column, cover	<0.2		<0.2		<0.2
PWQO (Interim)	0.005	0.005	0.005	0.005	0.005
Copper Concentrations (mg/L)					
Aerobic	0.03	0.01		0.022	
Reducing	0.15	0.274		0.276	
Flooded column, leachate	0.59		1.09		0.83
Flooded column, cover	0.12		0.273		0.14
PWQO (Interim)	0.001	0.001	0.001	0.001	0.001
Cobalt Concentrations (mg/L)					
Aerobic	0.79	0.80		0.43	
Reducing	17.2	15.6		11.2	
Flooded column, leachate	12.3		29.0		27.8
Flooded column, cover	0.53		3.69		2.67
PWQO	0.0009	0.0009	0.0009	0.0009	0.0009
Nickel Concentrations (mg/L)					
Aerobic	0.36	0.48		0.26	
Reducing	12.3	11.3		8.42	
Flooded column, leachate	8.69		22.7		23.4
Flooded column, cover	0.31		2.62		2.13
PWQO	0.025	0.025	0.025	0.025	0.025
Zinc Concentrations (mg/L)					
Aerobic	<0.005	<0.005		0.006	
Reducing	0.18	0.198		0.187	
Flooded column, leachate	0.453		1.20		1.23
Flooded column, cover	0.048		0.167		0.099
PWQO (Interim)	0.02	0.02	0.02	0.02	0.02

3.6.3 Water Flows within the Tailings Area

Based on the elevated contamination levels within the tailings solids and pore water, control of water flows is needed to ensure that no additional contaminated leachate is produced (through water contact with tailings solids) and that water contaminated in-situ is prevented from migrating offsite.

The primary source of water input to the Tailings Area comes from precipitation that falls directly onto the Tailings Area (area of 80,000 m^2) as well as run-on water from the surroundings (calculated as 99,000 m^2) (CH2M HILL, March 2002a). As water percolates through the crushed limestone cap and comes in contact with tailings materials, seepage flows out into areas downgradient of the site.

The two main conduits by which contaminated water can exit the Tailings Area are the west and east tailings dams seeps. Flow from seeps at the east dam discharges into Young's Creek, which eventually converges with the Moira River; however, the flow path is not direct (i.e. not the shortest path). The flow from seeps at the west dam discharges into the Moira River; however, the flow path is not direct (i.e. not the shortest path). Groundwater flow from the tailings also occurs; however, rates are relatively small compared to dam seepage rates, as discussed in the final report *Development of a Sitewide Water and Load Balance, Deloro Mine Rehabilitation Project* (CH2M HILL, March 2002a).

Water that leaves the Tailings Area can generally be grouped into the following four main categories:

- **Surface Water Runoff** – This is water that flows over the dams, flows through the dam above the red mud surface, or exits at a low-lying area along the south edge. Input water comes from precipitation and run-on water that infiltrates through the limestone layer to the red mud surface.
- **Dam Seepage** – Water that seeps through the east and west tailings dams through open cracks and holes at elevations below the red mud surface but above the base of the dams. Input water to this zone includes infiltrated water and overburden groundwater flow from areas surrounding the red mud tailings.
- **Overburden Groundwater Flow** – Water that exits the Tailings Area at elevations slightly lower than the bottom of the dams and becomes shallow overburden flow on the downstream side of the dams. Input water comes from infiltration and groundwater flow from areas surrounding the red mud tailings.
- **Bedrock Groundwater Flow** – Water that flows at elevations much lower than the bottom of the red mud tailings that has its source from infiltration of water through the red mud tailings as well as deep groundwater flow, which does not contact the red mud.

The estimated flow rates arising from each of the categories above are presented in Table 3.6, and are based on CH2M HILL's *Development of a Sitewide Water and Load Balance, Final Report* (March 2002a).

TABLE 3.6
ESTIMATED FLOW RATES FROM WEST AND EAST DAMS

	West Dam (m^3/yr)	East Dam (m^3/yr)	Total (m^3/yr)
Surface water runoff	15,123	38,075	53,198
Dam seepage	491	114	605
Overburden groundwater flow[1]	437	0	437
Bedrock groundwater flow[1]	102	114	216

[1] Groundwater flow estimates include only the area beneath the tailings dams.
Source: CH2M HILL, May 2002

Based on the data presented in Table 3.6, surface water runoff has been estimated to be the largest volume of water leaving the Tailings Area.

3.6.4 Contaminant Loading from the Tailings Area

Since 1985, the Ontario Clean Water Agency (OCWA) has been monitoring the quality of seepage water that comes from the Tailings Area (OCWA, 1997). Two monitoring stations referred to as DM4 and DM6, were established in the vicinity of the east and west tailings dams, as shown on Figure 2-2. The results represent water quality of surface water runoff and dam seepage. Using arsenic, cobalt, and copper as indices of contamination, Table 3.7 shows minimum, maximum, and average water quality concentration data for the period 1994–1996 along with the PWQO.

TABLE 3.7
SUMMARY OF DM4 AND DM6 YEARLY AVERAGES (1994-1996)

Parameter	West Dam (DM6)			East Dam (DM4)			PWQO
	Maximum	Minimum	Average	Maximum	Minimum	Average	
Arsenic (mg/L)	0.343	0.273	0.302	0.872	0.543	0.673	(0.005)
Cobalt (mg/L)	10.113	5.464	7.970	6.510	5.632	6.051	0.0009
Copper (mg/L)	1.721	0.394	0.914	0.128	0.027	0.079	(0.001–0.005)

Notes: PWQO = Provincial Water Quality Objectives, as presented in the CG&S *Deloro Mine Rehabilitation Project*, *Development of Closure Criteria Final Report*, October 1998a.
Items in ( ) refer to Interim PWQO.

Source: CH2M HILL, *Deloro Mine Rehabilitation Project, Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area,* Final Report, May 2002.

Due to the high frequency of sampling, it is expected that samples were taken in periods of both high and low flow and as a result represents an average of the various metal concentrations produced by various flow conditions.

Additional water quality data came from monitoring wells MW97-2, MW97-3, and MW97-4, which were installed at the west and east dams in 1997. These data were used to determine water quality of the groundwater flow.

Table 3.8 shows a yearly estimate of loadings from the Tailings Area to the Moira River and Young's Creek, through surface water runoff, dam seepage, and groundwater, based on the estimated flow rate contributions shown in Table 3.6 and additional (onsite) flow measurements obtained at the Tailings Area on November 4, 1998. These estimates suggest that cobalt loadings are relatively high, in comparison to other contaminant parameters.

When data presented in Table 3.8 are compared with current and target sitewide loadings to the Moira River and Young's Creek, an estimate of the relative contaminant load contribution (expressed as a percentage) can be obtained for the Tailings Area. These comparisons are shown in Table 3.9.

The total site loadings and loading targets presented in Table 3.9 were derived from the *Deloro Mine Rehabilitation Project, Development of Closure Criteria*, Final Report (CG&S, October 1998a).

Based on the above estimates, total cobalt loading from the Tailings Area represents approximately 71 percent of the total sitewide cobalt loading to the Moira River and Young's Creek. This example shows that the Tailings Area likely represents the single largest source of cobalt contamination on the Deloro mine property. By reducing the contaminant load of cobalt, it is likely that all other less significant metal loads will be similarly reduced.

3.6.5 Radioactivity Levels

A radiation survey conducted by SCIMUS Inc. in 1997 revealed the presence of radiation fields of approximately 3 μSv/h gamma and 33 μSv/h alpha and beta in the Tailings Area beneath the limestone cap. Further delineation indicated that the radioactivity was largely confined to the eastern portion of the red mud tailings deposits directly beneath the cap. The thickness of the radioactive tailings was generally 5 to 10 cm but varied from 5 to 40 cm.

Although the radioactive constituents of this material were considered immobile, radioactive substances such as radium can become mobile and can be leached from the tailings under acidic conditions (CH2M HILL, June 1999).

Despite the occurrences of radioactivity in the tailings deposits, the crushed limestone cover has been shown to provide an effective radiation shield. On top of the limestone cover, radiation fields are reduced to background levels. The limestone cover therefore eliminates the airborne dust hazard and prevents exposure to any receptors that might be on the Tailings Area surface. SRK (CH2M HILL, July 2002) stated that the limestone cap on the tailings surface is very effective in acting as a shield with regard to surface radioactivity exposure and airborne dust hazard and therefore the Tailings Area poses an insignificant human health risk in its present condition. However, surface erosion of the tailings has occurred in the past and should be prevented/addressed (CH2M HILL, June 1999).

Table 3.8
Yearly Metal Loadings at West and East Dams[1]

Parameter		West Dam (DM6)				East Dam (DM4)				Tailings Area Subwatershed
		Dam Seepage	Overburden Groundwater Flow[2]	Bedrock Groundwater Flow[2]	Total Predicted West Dam Flow and Loading	Dam Seepage	Overburden Groundwater Flow[2]	Bedrock Groundwater Flow[2]	Total Predicted East Dam Flow and Loading	Surface Water Runoff[2]
Flow	(m^3/yr)	491[3]	437	102	1030	114[3]	0	114	228	53,198
Arsenic	(kg/yr)	0.1	0.035	0.0003	0.14	0.08	0	0.0003	0.1	30
Cobalt	(kg/yr)	3.9	9.835	21.5	35.2	0.69	0	0.568	1.3	351
Copper	(kg/yr)	0.4	7.431	7.56	15.4	0.01	0	0.0002	0.01	17

Notes: [1] Source: *Development of a Sitewide Water and Load Balance* (CH2M HILL, March 2002a) and *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (CH2M HILL, May 2002)
[2] Groundwater flow estimates include only the area beneath the tailings dams
[3] Flow measured on November 4, 1998

TABLE 3.9
ESTIMATED CURRENT LOADING FROM THE FORMER DELORO MINE SITE (SITEWIDE AND TAILINGS AREA)

Contaminant	Moira River Loading	Young's Creek Loading	Total Sitewide Loading	Target Sitewide Loading	Target Sitewide Reduction	Tailings Area Loadings	Loading Contribution by Tailings Area
	kg/yr	kg/yr	kg/yr	kg/yr	%	kg/yr	%
Arsenic	4,951	154	5,105	620	88	30	0.6
Cobalt	536	13	549	112	80	388	71
Copper	619	3	622	124	80	32	5

Source: *Development of Closure Criteria* (CG&S 1998a) and *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (CH2M HILL, May 2002)

3.7 Summary

The Tailings Area of the Deloro Mine Site is located between the Moira River and Young's Creek. The tailings primarily comprise ferric hydroxide, or red mud, a waste by-product of the ore-refining process. The red mud tailings contain elevated levels of heavy metals, which are reflected in pore water concentrations. Water flowing out of the Tailings Area contains elevated levels of contaminants, particularly cobalt. The main sources of water input to the Tailings Area are precipitation, which falls directly on the site, and run-on water, which comes from the surrounding catchment area. The main source of output water from the Tailings Area comes from water flowing over the dams, through the dam above the red mud surface, and at a low-lying area along the south edge of the Tailings Area. The Tailings Area represents the single largest source of cobalt contamination on the Deloro property. As a result, the cobalt reduction target for the site cannot be achieved unless action is taken to reduce cobalt loading from the Tailings Area. By reducing the contaminant load of cobalt, it is likely that all other metal loads (e.g. arsenic, copper) will also be reduced, even though concentrations may remain stable or increase. Although portions of the red mud tailings have also been found to contain radioactivity, the crushed limestone cover provides an effective radiation shield.

The selected alternative will need to address the local variations in site conditions and properties. Addressing these variations will therefore form a part of evaluating the remedial alternatives.

4. Alternatives Evaluation Process

4.1 Strategic Direction for Site Cleanup

In the early 1990s, MOE staff from Southeast Region (now MOE Eastern Region) reviewed the Deloro Mine Site Project with the then MOE Management Committee to determine a strategic direction for final site cleanup. The Committee was composed of several MOE Assistant Deputy Ministers (ADMs), the Deputy Minister (DM) and the Minister, as well as an ADM and Director from the Ministry of Northern Development and Mines (MNDM).

Based on a detailed analysis of site conditions and on previous experience gained in similar situations, the Committee recommended that onsite waste management options be favoured as primary remediation techniques to rehabilitate the site. The main reason for adopting this approach was the realization that complete cleanup to natural background levels would be extremely costly and may not represent the most prudent expenditure of public funds. It was also recommended that the cleanup work proceed under an exemption to the provincial Environmental Assessment Act. These two recommendations were endorsed by the Ontario Minister of the Environment in October 1991 and funds were then allocated to retain professional services to develop and implement a cleanup plan under the authority of the MOE. The latter recommendations were identified as “fundamentals” in the *Deloro Rehabilitation Plan* produced by the Southeast Region office of the MOE (now the Eastern Region office of the MOE) in September 1992 and formed an integral part of the request for proposal that was issued by the MOE in 1996 to select a consulting engineering firm to develop and implement a remedial plan for the Deloro Mine Site.

4.2 Closure Objectives

As described in the report entitled *Deloro Mine Rehabilitation Project - Development of Closure Criteria, Final Report* (CG&S, October 1998a), and in the above section, the strategic direction for site cleanup involves onsite management of wastes through isolation and containment methods as primary remediation techniques. Consequently, a pragmatic approach has been adopted where mitigative measures are directed at risk reduction. This translates into the following project objective:

> *To successfully rehabilitate the Deloro Mine Site to mitigate any unacceptable impacts on human health or the environment in compliance with relevant environmental policies and regulations*

To satisfy this objective, specific site-wide and distinct area closure objectives were developed. The site-wide closure objectives are as follows:

1. Reducing the loading of arsenic and other contaminants to the Moira River
2. Compliance with appropriate regulations and policy
3. Satisfy the general intent of the Mining Act and related draft regulations
4. Reducing/controlling impact/risk to acceptable levels
5. Demolition of unneeded buildings to ground level

6. Prioritizing remedial action implementation according to risk reduction
7. Minimizing perpetual operation and maintenance
8. Restoration of the site to reflect its natural surroundings
9. Securing the site for the indefinite future
10. Managing the wastes over the smallest possible area

These site-wide closure objectives were further refined into area-specific closure objectives for each of the areas of the site. The area-specific closure objectives for the Young's Creek Area are presented in Section 5.1.

4.3 Overview of the Process to Generate and Evaluate Alternatives

The process applied by CH2M HILL to generate potential remedial alternatives for all areas of the Deloro site is illustrated in Figures 4-1 to 4-3. Initially, conceptual remediation methods that could have addressed some or all of the issues identified for each respective area of the site were identified. For instance, a method may address groundwater issues but not impacted sediment. These methods were evaluated with a screening process to identify which methods had the greatest potential to address the issues at the site, either alone or in combination with other methods. Improbable methods that did not have significant potential to contribute to a viable solution were eliminated early in the process. This resulted in a list of primary remediation methods that were retained for further evaluation.

The primary remediation methods were combined with enhancing features based on the judgement and experience of the project team to create a number of comprehensive remediation alternatives that addressed all of the environmental issues at the site. These comprehensive remediation alternatives were subsequently evaluated in a two-step process. The screening level evaluation again served to eliminate comprehensive remediation alternatives (as opposed to conceptual remediation methods that have been previously screened) that were unlikely to meet all of the remediation needs for the area. This second level of screening led to a short list of comprehensive remediation alternatives that were the subject of a more detailed evaluation. The detailed evaluation led to the identification of a recommended remediation alternative, which would be developed further and subsequently implemented to address the environmental issues at the site.

4.4 Generation of Comprehensive Remediation Alternatives

Significant efforts were invested through the years to characterize environmental conditions (i.e. soil, surface water, groundwater, air, human health risk, and ecological conditions) for all areas of the site. Such characterization studies were necessary to identify contaminants of concern, quantify contaminant concentrations and volumes, determine the media into which the contaminants were found, and assess contaminant mobility. It is as a function of these characteristics that potential conceptual remediation methods were initially generated.

The alternatives generation process involved consideration of the strategic approach described in Section 4.1, identification of conceptual remedial methods that CH2M HILL has either used on similar projects in the past, or identified in the scientific literature for the

contaminants and media of concern, as well as specific exclusionary criteria dealing with the following:

- Effectiveness of the conceptual methods in question to remediate the site
- Satisfaction (in principle) of government regulations and guidelines
- Pre-established design closure criteria

These criteria were designed to eliminate improbable conceptual remediation methods early in the process so that valuable time and resources were not expended in the completion of a more detailed evaluation.

The methods developed for consideration were not intended to be an exhaustive evaluation of all conceivable methods, but a focused assessment of readily identifiable and proven methods that had good potential for successful application at the site. Consideration of experimental or developmental methods was considered beyond the scope of this evaluation. Professional judgement and practical considerations factored into the range and diversity of methods considered. For instance, where a proven and effective method was readily identifiable and cost-effective, limited consideration was made of other methods.

The first exclusionary criterion, the effectiveness of the conceptual remediation method, was used to evaluate the expected effectiveness of the method in solving the problem identified for the area (i.e. Can the conceptual remediation method contribute to a significant attenuation of unacceptable impacts on human health or the environment by way of reducing a component of the contaminant load?). The second criterion, the satisfaction of government regulations and guidelines, served to evaluate the capacity of the conceptual remediation method to meet relevant government legislation and guidelines. The third criterion, design closure criteria, was used to assess whether the conceptual remediation method was likely to satisfy the area specific design criteria, a combination of the closure criteria and remediation targets outlined below.

These design criteria were developed from a risk based approach that is summarized in the report entitled *Deloro Mine Rehabilitation Project - Development of Closure Criteria, Final Report* (CG&S, October 1998a). The risk based approach was used to identify areas of the site that pose the greatest risk and consequently served to prioritize remedial action to obtain the greatest reduction of contaminant release from the site as well as overall exposure to contaminants. Using risk assessment, remediation targets were set as follows:

1. Surface water from Young’s Creek and the Moira River should satisfy, on average, the Interim Provincial Water Quality Objectives (PWQO) for three key contaminants (i.e. arsenic, cobalt and copper) at the Highway 7 crossing located approximately 600 m downstream (i.e. south) of the site.
2. Post-closure onsite arsenic concentration in air and soil should be, on average, below a concentration that will ensure that the probability of incremental lifetime cancer risk for onsite workers and potential recreational users of the site is less than 1:100,000.

To achieve these targets, site-wide closure objectives were translated to area-specific closure objectives (as stated in Section 5.1) that were refined into closure criteria that specifically address the following:

- Physical aspects

  - Design service life
  - Design floods
  - Seismic considerations
  - Minimum factors of safety
  - Perpetual disruptive forces

- Chemical aspects
  - Human health
  - Aquatic life
  - Terrestrial habitat

- Radiological aspects

These closure criteria will become closure plan design parameters for the selected remediation alternative, as described in the *Deloro Mine Rehabilitation Project - Development of Closure Criteria, Final Report* (CG&S, October 1998a).

4.4.1 Screening of Conceptual Remediation Methods

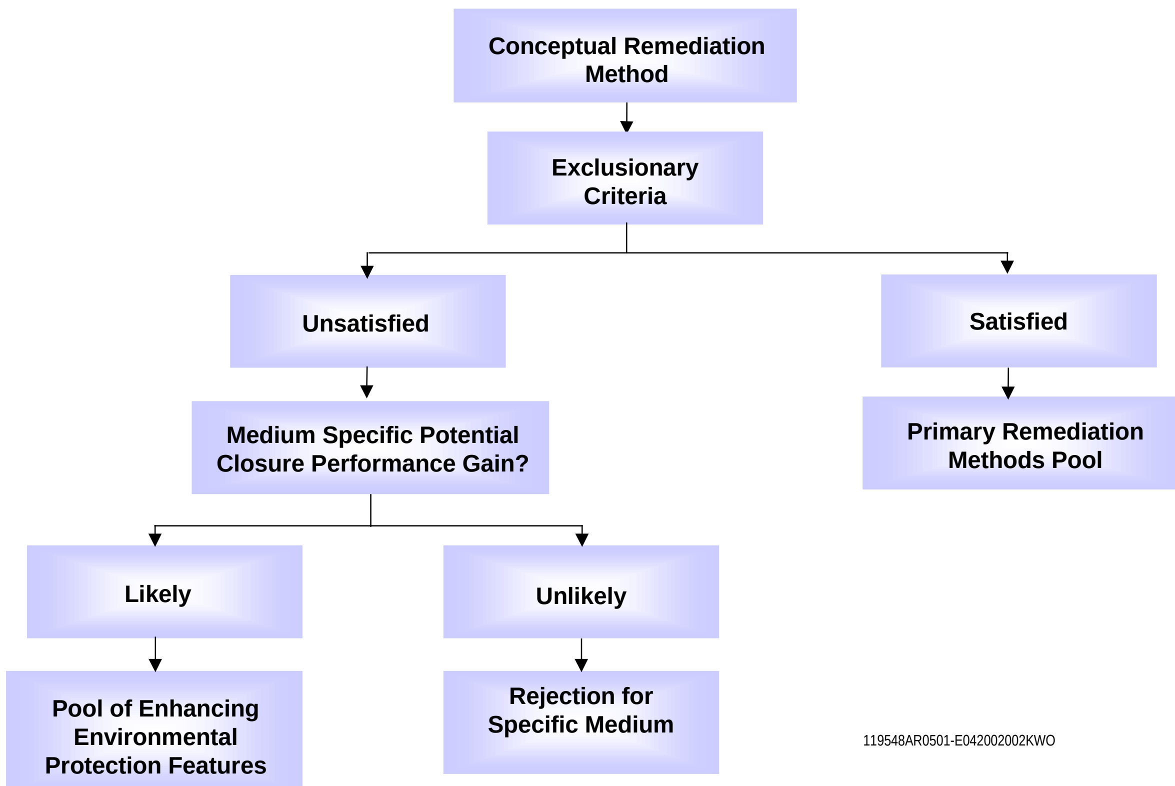
Each conceptual remediation method was consequently evaluated to determine whether it could (yes) or could not (no) meet the exclusionary criteria presented above. A "no" to any of these criteria eliminated the conceptual remediation method as a primary remediation method. A primary remediation method is defined as a method that had significant potential to address most of the environmental issues in this area of the site without further augmentation or enhancement. All criteria carried equal weight in the evaluation process; therefore, their order of appearance does not reflect their relative importance. Table 4.1 further synthesizes the intent of the exclusionary criteria used to generate remediation alternatives.

TABLE 4.1
EXCLUSIONARY CRITERIA – SCREENING OF CONCEPTUAL REMEDIATION METHODS

Exclusionary Criteria	Considerations	Measure
Effectiveness	Does the conceptual remediation method have the potential to solve one or more aspects of the problem? (i.e. Can it contribute to a significant attenuation of any unacceptable impacts on human health or the environment by way of reducing a component of the contaminant load?)	Yes – The conceptual remediation method has the potential to significantly reduce contaminant loads to the environment. No – The conceptual remediation method does not have the potential to significantly reduce contaminant loads to the environment.
Government Regulations and Guidelines	Does the conceptual remediation method conform in principle to applicable government regulations and guidelines relating to site rehabilitation? (e.g. Guideline for Use at Contaminated Sites, Mining Act and Rehabilitation Guidelines?)	Yes – The conceptual remediation method is more likely to conform. No – The conceptual remediation method is less likely to conform.
Design Closure Criteria	Is the conceptual remediation method likely to satisfy design closure criteria pertaining to site specific risk assessment of human health and environmental impacts if developed in greater detail?	Yes – The conceptual remediation method has the potential to satisfy design criteria. No - The conceptual remediation method has no potential to satisfy design criteria.

Rejection as a primary remediation method did not exclude further consideration of the method to augment another conceptual remediation method, particularly if the former showed significant potential to control the release or minimize the mobility of contaminants in a specific medium (groundwater, surface water, soil or air). Some methods were retained based on their potential for combination with other methods to create a comprehensive solution to the environmental issues in an area. Such combinations were termed "Comprehensive Remediation Alternatives". Other methods were retained as potential enhancements, which formed redundancies in the design, such as multiple barriers to contaminant release/migration. Figure 4-1 illustrates the process used to screen conceptual remediation methods.

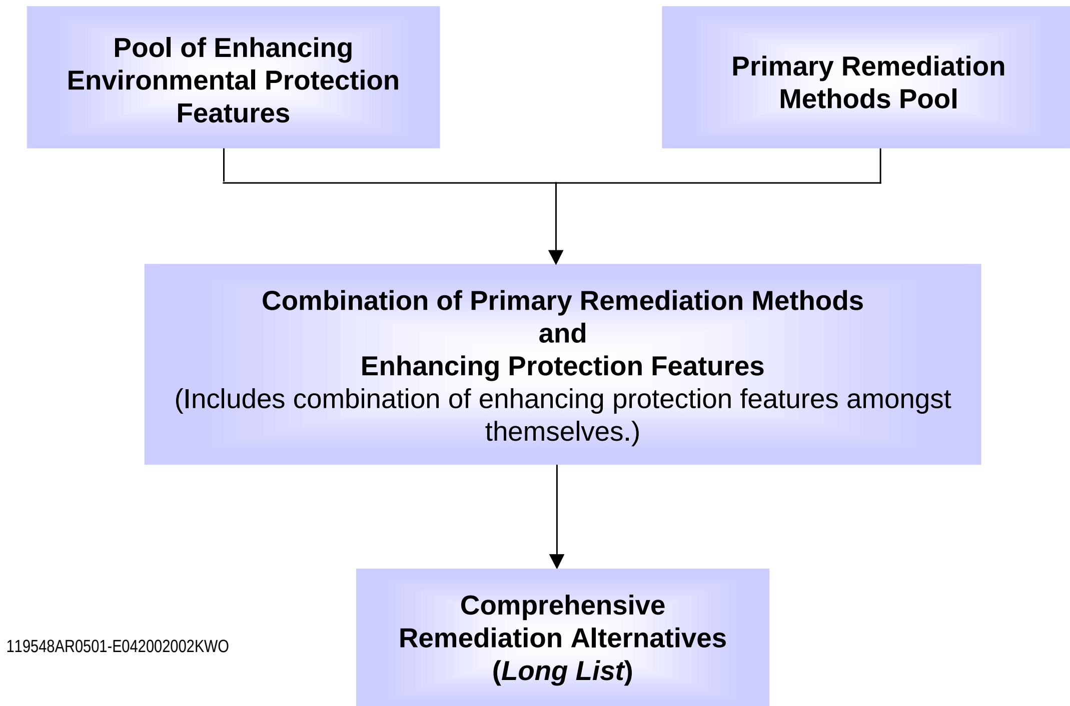
FIGURE 4-1
SCREENING OF CONCEPTUAL REMEDIATION METHODS – SCHEMATIC DIAGRAM



4.4.2 Development of Comprehensive Remediation Alternatives

Figure 4-2 schematically illustrates the process used to generate comprehensive remediation alternatives for further consideration. Alternatives were developed from the list of primary remediation methods that have passed the screening level evaluation. Comprehensive remediation alternatives were developed to create potential solutions that addressed all of the environmental issues or problems in each area. Where primary remediation methods have been identified through the screening process, the team considered how the method could be augmented or enhanced to address all the issues. In developing comprehensive remediation alternatives, the project team considered the multiple goals and objectives that must be achieved for an acceptable solution. In particular, comprehensive remediation alternatives were developed to mitigate the release of contaminants to the environment along various exposure or migration pathways.

FIGURE 4-2
DEVELOPMENT OF COMPREHENSIVE REMEDIATION ALTERNATIVES – SCHEMATIC DIAGRAM



In addition to developing comprehensive remediation alternatives that just meet the project requirements, our team has also considered augmenting or enhancing these alternatives to provide greater certainty through additional levels of protection. These enhancing environmental protection features were considered as design redundancies or contingencies that provide multiple barriers to contaminant release/migration and serve to increase the level of confidence that an alternative will achieve the project goals.

4.5 Evaluation of Comprehensive Remediation Alternatives

The evaluation process that was developed to select a recommended remediation alternative for the area of the site relied on a qualitative assessment of the comprehensive remediation alternatives. It allowed the evaluation to focus on the alternatives that are most promising to satisfy the closure objectives while avoiding consideration of superfluous alternatives.

Comprehensive remediation alternatives were evaluated using the process illustrated in Figure 4-3. The first step in selecting a recommended remediation alternative was to compare all comprehensive remediation alternatives (the "long list") to a second set of exclusionary criteria identified in Table 4.2 as a screening exercise. This step ensured that the combination of an environmental protection feature with a primary remediation method did not undermine the potential effectiveness of the latter. The exercise led to the construction of a "short list" of comprehensive remediation alternatives from which the recommended remediation alternative was selected. It is important to recognize that while the first set of exclusionary criteria shown in Table 4.1 deals mainly with the evaluation of *methods* which have the potential to form *part* of a comprehensive solution, such as reduction of a component of contaminant load to the environment, the second set of

exclusionary criteria shown in Table 4.2 focuses on the screening of *comprehensive solutions* and their ability to achieve an overall reduction of contaminant load from the area.

TABLE 4.2
EXCLUSIONARY CRITERIA – SCREENING OF COMPREHENSIVE REMEDIATION ALTERNATIVES

Exclusionary Criteria	Considerations	Measure
Effectiveness	Does the comprehensive remediation alternative solve the problem? (i.e. Can it contribute to a significant attenuation of any unacceptable impacts on human health or the environment by way of reducing contaminant loads from the entire Area?)	Yes – The comprehensive remediation alternative has the potential to significantly reduce contaminant loads to the environment. No – The comprehensive remediation alternative does not have the potential to significantly reduce contaminant loads to the environment.
Government Regulations and Guidelines	Does the comprehensive remediation alternative conform to applicable government regulations and guidelines relating to site rehabilitation? (e.g. Guideline for Use at Contaminated Sites, Mining Act and Rehabilitation Guidelines)	Yes – The comprehensive remediation alternative is more likely to conform. No – The comprehensive remediation alternative is less likely to conform.
Design Closure Criteria	Will the comprehensive remediation alternative satisfy design closure criteria pertaining to site specific risk assessment of human health and environmental impacts?	Yes – The comprehensive remediation alternative has the potential to satisfy design criteria. No – The comprehensive remediation alternative has no potential to satisfy design criteria.

The detailed evaluation of the short-listed comprehensive remediation alternatives was completed by comparing them against a series of evaluation criteria that not only reflected the objectives of the project but that also captured the essence of environmental assessment criteria that are commonly applied by the MOE when it is required to evaluate impacts associated with a given project. Appendix A illustrates how the detailed evaluation criteria used in the process described here and the environmental assessment screening criteria are related.

The detailed evaluation criteria consist of four categories of criteria listed below. All criteria carry equal weight in the evaluation process and consequently their order of appearance does not reflect the relative importance of each criterion.

- Technical Considerations
  - Reliability
  - Compatibility with existing system
  - Ease of implementation
- Costs
  - Operation and maintenance costs
  - Capital costs

- Social Considerations
  - Public acceptance
  - Risk to public
  - Constraint for recreational use
  - Negative impact to private properties
  - Visual character of the area
  - Risk to workers
- Natural Environment
  - Geochemistry
  - Terrestrial habitats
  - Floodplain
  - Fish habitats

Table 4.3 summarizes the intent of the detailed evaluation criteria. Further descriptions of each category of criteria are provided below.

TABLE 4.3
DETAILED EVALUATION CRITERIA – COMPREHENSIVE REMEDIATION ALTERNATIVES

Criteria	Considerations	Measure
Technical Considerations		
Reliability	Ability of the alternative to satisfactorily control discharge quality on a regular and reliable basis	Good – very reliable, few performance problems Fair – somewhat reliable, some performance problems Poor – not reliable, many performance problems
Compatibility with Existing System	Ability of the alternative to adapt to the existing site conditions and system	Good – very compatible, few technical problems Fair – somewhat compatible, some technical problems Poor – not compatible, many technical problems
Ease of Implementation	Ability of the alternative to be easily implemented from a technical perspective (e.g. land availability, timing, approval requirements)	Good – easily implemented, few problems Fair – somewhat easily implemented, some problems Poor – not easily implemented many problems encountered
Costs		
Operation & Maintenance Costs	Relative measure of O&M costs compared to other alternatives	High – relatively high operating and maintenance costs Moderate – relatively moderate operating and maintenance costs Low – relatively low operating and maintenance costs
Capital Costs	Relative measure of capital costs compared to other alternatives	High – relatively high capital costs Moderate – relatively moderate capital costs Low – relatively low capital costs
Social Considerations		
Public Acceptance	The potential for the comprehensive remediation alternative to be accepted by the public	High – minimal or no potential for some reservation from the public Moderate – potential for some reservation from the public Low – potential for significant reservation from the public

TABLE 4.3
DETAILED EVALUATION CRITERIA – COMPREHENSIVE REMEDIATION ALTERNATIVES

Criteria	Considerations	Measure
Risk to Public	The potential for the comprehensive remediation alternative to create a risk to public safety	High – potential for significant risk to public safety Moderate - potential for some risk to public safety Low – potential for low/no risk to public safety
Constraint for Recreational Use	The potential for the comprehensive remediation alternative to create constraints for recreational opportunities	High – potential for significant constraints on recreational opportunity Moderate – potential for some constraints on recreational opportunity Low – minimal or no constraints for recreational opportunity
Negative Impact to Private Properties	The potential for the comprehensive remediation alternative to produce a negative impact to private properties	High – potential for significant negative impact to surrounding private properties Moderate – potential for some negative impacts on surrounding private properties Low – minimal or no negative impacts on surrounding private properties
Visual Character of the Area	The potential for the comprehensive remediation alternative to impact the visual character of the area	High – potential to severely impact the visual character of an area Moderate – potential to have some impacts on the visual character of an area Low – minimal impacts on the visual character of an area
Risk to Workers	The potential for the comprehensive remediation alternative to create a risk to workers	High – potential for significant risk to workers Moderate – potential for some risk to workers Low – potential for low/no risk to workers
<u>Natural Environment</u>		
Geochemistry	The potential for the alternative to improve the geochemistry of the area	High – high potential to improve the geochemistry Moderate – some potential to improve the geochemistry Low – low potential to improve the geochemistry
Terrestrial Habitats	The potential of an alternative to improve terrestrial habitats	Good – potential to significantly improve terrestrial habitats Fair – potential to somewhat improve terrestrial habitats Poor – minimal or no improvement to terrestrial habitats
Floodplain	The potential of the alternative to disrupt/intrude upon the floodplain	High – potential to disrupt/intrude upon floodplain resulting in potentially significant impacts to the system. Moderate – potential to cause some disturbance or intrusion into floodplain; impacts less severe Low – minimal/no disturbance; alternative offers the opportunity to “cleanup” floodplain.
Fish Habitats	The potential of the alternative to cause disturbance to or loss of fisheries habitat	High – potential to cause disturbance or loss of significant area of fisheries habitat, significant compensation measures required; Moderate – potential to cause some disturbance or loss of fisheries habitat, some mitigation required; Low – minimal disturbance or no loss of fisheries habitat

4.5.1 Technical Considerations

The first technical criterion dealt with the comprehensive remediation alternative's technical reliability in mitigating human health and environmental impacts from the area. Surface water runoff and/or groundwater discharge have been identified as the main loading sources for the influx of arsenic and metals to the Moira River and Young's Creek. The ability to reduce the contact between the groundwater and the wastes or redirect the groundwater cross flow along with other water inputs to the area also form the basis for the evaluation of the comprehensive remediation alternative's reliability. The ability of the alternative to satisfactorily control discharge on a regular and reliable basis over the long term was considered paramount. These discharges and water inputs can be reduced by selecting or combining some of the following design principles:

- Reducing the amount of precipitation that infiltrates into the impacted materials
- Reducing the amount of groundwater contacting the impacted materials
- Lowering the static groundwater table below the lower horizon of impacted materials
- Intercepting surface water runoff and divert the flow away from the impacted materials
- Minimizing the onsite retention time of any uncontaminated water
- Reducing the contact area of the impacted materials
- Placing the wastes above the water table
- Reducing the rate at which water moves through the wastes

The second criterion examined the comprehensive remediation alternative's ability to operate in tandem with existing systems operating at the site, if present, notably the existing groundwater pumping and arsenic treatment system in the Industrial Area.

Finally, the ease to construct and implement the comprehensive remediation alternative was examined as a precursor to following criteria. Issues such as sufficient workspace, available technologies and complexity were addressed.

4.5.2 Costs

The second category of criteria used for the evaluation of rehabilitation alternatives was costs. Capital, construction, and operation and maintenance costs (O&M) for the comprehensive remediation alternatives were considered relative to each other. Costs were based upon the engineering complexity and work required to implement the alternative.

Costs were estimated on the basis of conceptual remediation plans derived from the conceptual remediation alternatives identified earlier in this process. Budgetary estimates were calculated for this evaluation process and meant to provide an indication of the magnitude of the cost associated with each comprehensive remediation for comparison purposes only. The cost estimates are presented in 2002 dollars.

4.5.3 Social Considerations

Criteria in this category addressed the ability of the remediation alternatives to meet social needs and expectations such as future recreational use of the property, impacts of the works on private property and the overall visual character of the site.

An important step in evaluating the alternatives was the ability to mitigate the threat to human health. The risk to human health was considered for the general public,

rehabilitation staff and workers involved in ongoing operation and maintenance of the site, based on the potential for acute and long-term effects.

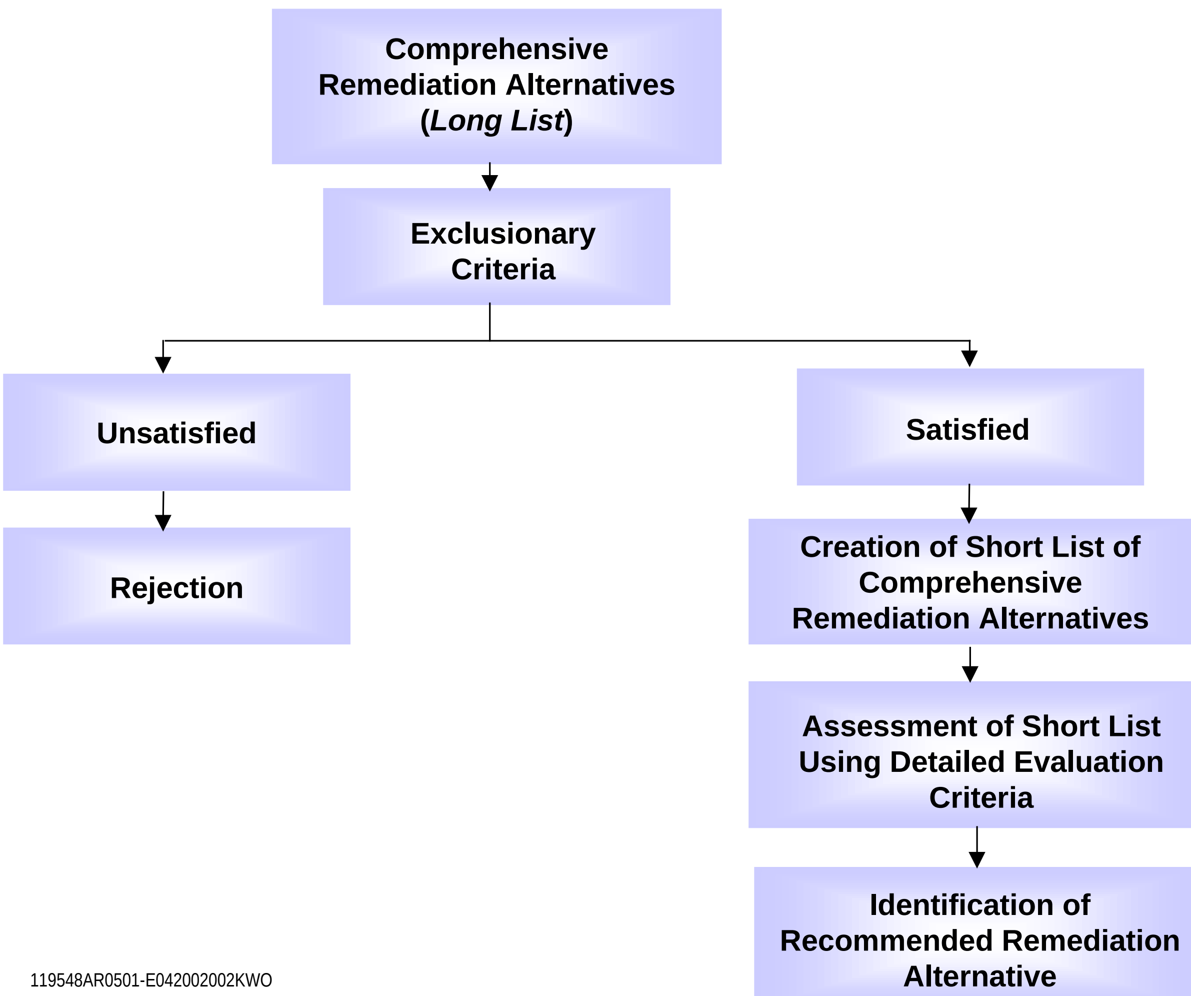
4.5.4 Natural Environment

This category encompasses all of the natural environmental components not covered in the above subsection. This evaluation examined the alternative's ability to improve or protect the following:

- Geochemistry (Surface water and groundwater quality)
- Terrestrial habitats
- Floodplains
- Fish habitats

Figure 4-3 schematically illustrates the process used for the detailed evaluation of the short-listed comprehensive remediation alternatives to determine the recommended remediation alternative.

FIGURE 4-3
EVALUATION OF COMPREHENSIVE REMEDIATION ALTERNATIVES – SCHEMATIC DIAGRAM



4.6 Summary

The strategic direction of the Deloro Mine Site Cleanup Project in the early 1990s was to manage wastes onsite. Based on the overall project objective, which is to mitigate any unacceptable impacts on human health and the environment, a process was developed to generate "reasonable" comprehensive remediation alternatives for the area. The system relied on the use of exclusionary criteria to identify conceptual remediation alternatives that may be applicable for the area. It also allowed for the development of enhancing environmental protection features that could augment the level of protection offered by any given remediation alternative.

Following the generation of a long list of comprehensive remediation alternatives, each alternative was evaluated against two sets of criteria to identify a recommended remediation alternative. This evaluation of the alternatives against the first set of criteria resulted in a short list of comprehensive remediation alternatives that was evaluated in greater detail using the second set of criteria (i.e. the detailed evaluation criteria). The latter criteria provided a more detailed level of comparison of each alternative with respect to the others and allowed the selection of a recommended remediation alternative for the area.

An alternative was recommended that satisfied the greatest number of criteria and provided the greatest value to MOE based on the professional judgement of the CH2M HILL team.

5. Development and Evaluation of Alternatives

The development and evaluation of remediation alternatives for the Tailings Area is driven by the closure objectives discussed in the following section.

5.1 Remedial and Closure Objectives

The following closure objectives developed for the Tailings Area reflect the overall remedial objectives for the Deloro site, as stated in Section 4.2:

1. Develop a rehabilitation closure plan supported by a Site Specific Risk Assessment (SSRA)
2. Develop/implement risk reduction plans according to site-wide priorities
3. Implement measures to eliminate exposed wastes at ground surface
4. Manage contaminated groundwater/seepage/runoff
5. Promote revegetation of the Tailings Area to match native conditions (i.e. to match current natural surroundings)
6. Contain tailings for the long term consistent with accepted design practice
7. Provide assurance of dam stability through testing and, if required, dam stabilization

5.2 Identification of Conceptual Remediation Methods

The crushed limestone cover installed by the MOE over the surface of the Tailings Area has effectively eliminated the airborne release of dust and isolated radioactivity from the tailings. Consequently, the remaining objective is to reduce the amount of metals (especially cobalt, copper, nickel, and zinc) and arsenic leaving the Tailings Area through water movement. Therefore, the remediation alternatives that were generated focus on reducing contaminant loading associated with water movement.

As described in Section 4.3, the first step in the generation of remediation alternatives for the Tailings Area consisted of identifying conceptual remediation methods that have been applied in similar situations. The conceptual remediation methods that were identified for the Tailings Area are:

- Do nothing
- Establish a wetland over the Tailings Area surface
- Cover the surface of the Tailings Area with soil and vegetation
- Establish a permanent water cover over the Tailings Area
- Divert surface runoff away from the Tailings Area
- Collect and treat seepage and groundwater using a conventional or natural treatment system

Each of these conceptual remediation methods is described in general terms below.

5.2.1 Do Nothing

This method consists of not modifying current site conditions in any way and as such, it does not constitute a “genuine” conceptual remediation method. However, the ”do nothing” scenario is typically considered in evaluation schemes such as this one because it helps determine current site conditions in terms of contaminant release pathways, exposure routes and contaminant loading. It constitutes a baseline against which other conceptual methods can be compared.

5.2.2 Establish a Wetland Over the Tailings Area Surface

Geocon (1986) initially examined the placement of a wetland cover over the Tailings Area. This approach was based on stabilizing the long-term chemistry of the wetland and eliminating dust problems along the red mud surface. It was recommended at a time when the tailings surface was exposed prior to the placement of the limestone cover over the tailings surface. However, the tailings were subsequently confirmed to be non-acid generating, indicating that they would release more contaminants under reducing conditions, which should be avoided.

5.2.3 Cover the Surface of the Tailings Area with Soil and Vegetation

This conceptual remediation method consists of covering the entire surface of the Tailings Area with topsoil and vegetation to minimize infiltration into the tailings. Such covers typically consist of multiple layers of soil of varying grain-sizes (clays to sands) that are combined in such a way that water that infiltrates into the topsoil does not migrate further below because of the presence of a compacted clay layer at the interface of the tailings and the cover itself. In this fashion, infiltrated water can be stored in the topsoil up to the soil moisture holding capacity and is evapotranspirated by the vegetation during the spring, summer, and fall growing period of each year.

5.2.4 Establish a Permanent Water Cover Over the Tailings Area

This conceptual remediation method involves the construction of water-retaining dams around the perimeter of the Tailings Area to establish a permanent water cover on top of the tailings. This has been suggested in earlier reports, as the use of permanent water cover is a common means to reduce oxidation of potentially acid-generating tailings. This approach was again recommended at a time when the tailings surface was exposed prior to the placement of the limestone cover over tailings surface. However, the tailings were subsequently confirmed to be non-acid generating, indicating that they would release more contaminants under reducing conditions, which should be avoided.

5.2.5 Divert Surface Runoff Away From the Tailings Area

Another conceptual remediation method that was considered was the construction of a surface water interceptor ditch at the north end of the Tailings Area to divert the stormwater flow around the tailings impoundment area. Diversion ditching to reduce surface run-on is expected to reduce the amount of water available to infiltrate into the tailings and, consequently, reduce the contaminant loadings to groundwater.

5.2.6 Collect and Treat Seepage and Groundwater Using a Conventional or Natural Treatment System

This conceptual remediation method consists of collecting seepage that escapes the Tailings Area through the east and west tailings dams and from the fractured bedrock on which the dams are built. Both seepage and groundwater could be collected by a series of sumps excavated or drilled along the dams.

5.3 Screening of Conceptual Remediation Methods

5.3.1 Screening of Long List of Conceptual Remediation Methods

The second step used in the generation of remedial alternatives was to compare the conceptual remediation methods described above to the set of exclusionary criteria identified in Table 4.1. As explained in Section 4.3, these criteria were designed to eliminate, early in the process, improbable conceptual remediation methods for the area under consideration. From the six conceptual remediation methods listed above, only two satisfied the exclusionary criteria and were retained as primary remediation methods. Table 5.1 details the rationale used to exclude the four conceptual remediation methods that were rejected as primary remediation methods. The "Do Nothing" alternative has been included in Table 5.1 as a benchmark comparison point, as noted in Section 5.2.1.

Primary remediation methods retained for the Tailings Area are:

- Cover with soil and vegetation
- Collect and treat seepage and groundwater

Among the four conceptual remediation methods that were rejected as primary remediation methods, only one (i.e. divert surface runoff away from the Tailings Area) was judged to be adequate as an enhancing environmental protection feature.

5.3.2 Development of Comprehensive Remediation Alternatives

The last step in generating the remediation alternatives consisted of combining the primary remediation methods and adding enhancing environmental protection features. The main components that were used to generate the comprehensive remediation methods are:

- Cover with soil and vegetation
- Collect and treat seepage and groundwater
- Divert surface runoff away from the Tailings Area

TABLE 5.1
SCREENING OF CONCEPTUAL REMEDIATION METHODS

Conceptual Remediation Method	Exclusionary Criteria: Effectiveness	Exclusionary Criteria: Government Regulations and Guidelines	Exclusionary Criteria: Design Closure Criteria	Selected as a Primary Remediation Method?	Selected as Enhancing Environmental Protection Feature or Component of Primary?
Do Nothing	No – Does not have the potential to significantly reduce contaminant loads to the environment	No – Doing nothing would not conform to applicable government regulations and guidelines	No – The conceptual remediation method has no potential to satisfy design closure criteria as main contaminant release pathways will remain unattenuated	No	No
Wetland Cover	No – Does not have the potential to significantly reduce contaminant loads to the environment as the presence of a wetland could lead to chemically reducing conditions which may lead to greater contaminant release to the Moira River and Young's Creek	No – Establishing a wetland over the surface of the tailings is less likely to conform to government regulations and guidelines	No – The conceptual remediation method has no potential to satisfy design criteria	No	No
Soil Cover and Vegetation	Yes – Does have the potential to significantly reduce contaminant loads to the environment as contact between surface water and the tailings will be minimized	Yes – Building a soil cover and vegetating; it is likely to conform to government regulations and guidelines	Yes – The conceptual remediation method has the potential to satisfy design criteria	Yes	No
Permanent Water Cover over the Tailings Area	No – Does not have the potential to significantly reduce contaminant loads to the environment as a permanent water cover may lead to additional contaminant release to the Moira River and Young's Creek	No – Constructing a permanent water cover over the Tailings Area would not conform to applicable government regulations and guidelines	No – The conceptual remediation method has no potential to satisfy design criteria	No	No
Divert Surface Runoff Away From the Tailings Area	No – Does not have the potential to significantly reduce contaminant loads to the environment as water inputs from precipitation falling on the surface and subsurface groundwater cross flow will continue to result in release of contaminants to the environment	No – Only diverting surface water runoff away from the Tailings Area would not conform to applicable government regulations and guidelines	No – The conceptual remediation method on its own has no potential to satisfy design criteria	No	Yes
Collect and Treat Seepage and Groundwater	Yes – Does have the potential to significantly reduce contaminant loads to the environment	Yes – Collecting and treating seepage and groundwater is likely to conform to government regulations and guidelines	Yes – The conceptual remediation method has the potential to satisfy design criteria	Yes	Yes

In total, six comprehensive remediation alternatives were generated, these include the following:

1. Cover the surface of the Tailings Area with soil and vegetation
2. Cover the surface of the Tailings Area with soil and vegetation and divert surface runoff away from the Tailings Area
3. Cover the surface of the Tailings Area with soil and vegetation and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to a natural treatment system [i.e. wetland and peat bed].)
4. Cover the surface of the Tailings Area with soil and vegetation and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to the existing onsite wastewater treatment plant.)
5. Cover the surface of the Tailings Area with soil and vegetation, divert surface runoff away from the Tailings Area and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to a natural treatment system [i.e. wetland and peat bed].)
6. Cover the surface of the Tailings Area with soil and vegetation, divert surface runoff away from the Tailings Area and collect and treat seepage and groundwater (In this option, collected seepage and groundwater are directed to the existing onsite wastewater treatment plant.)

5.3.3 Screening of Comprehensive Remediation Alternatives

Because all comprehensive remediation alternatives resulted from a combination of primary remediation methods and/or enhancing environmental protection features, they were evaluated against the second set of exclusionary criteria (see Table 4.2) for remediating the entire Area, as described in Section 4.5, to ensure that the addition of protection features to the primary remediation methods did not violate the criteria. A summary of whether the comprehensive remediation alternatives did or did not satisfy these criteria is presented in Table 5.2. In the case of the Tailings Area, the six comprehensive remediation alternatives satisfied the exclusionary criteria and constitute the short list of remedial alternatives that was evaluated in detail.

5.3.4 Short List of Comprehensive Remediation Alternatives

A detailed description of the comprehensive remediation alternatives that satisfied the exclusionary criteria is provided below. Each description includes a discussion of the following points:

- Expected performance relative to dissolved contaminant loading and the Interim Provincial Water Quality Objectives (IPWQO) in Young’s Creek and the Moira River at the intersection of these water courses and Highway 7
- Levels of redundancy offered by the comprehensive remediation alternative

TABLE 5.2
SCREENING OF COMPREHENSIVE REMEDIATION ALTERNATIVES

Comprehensive Remediation Alternative	Exclusionary Criteria			Selected?
	Effectiveness	**Government Regulations and Guidelines**	**Design Closure Criteria**	
Soil cover and vegetation	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it decreases vertical and subsequently horizontal water movement through the tailings	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes
Soil cover and vegetation – Divert surface runoff away from the Tailings Area	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it minimizes vertical and subsequently horizontal water movement through the tailings	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes
Soil cover and vegetation – Collect and treat seepage and groundwater (natural treatment system [wetland and peat bed])	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it minimizes vertical water movement through the tailings as well as the volume of impacted seepage/groundwater that leaves the Tailings Area	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes
Soil cover and vegetation – Collect and treat seepage and groundwater (existing onsite wastewater treatment plant)	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it minimizes vertical water movement through the tailings as well as the volume of impacted seepage/groundwater that leaves the Tailings Area	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes
Soil cover and vegetation – Divert surface runoff away from the Tailings Area – Collect and treat seepage and groundwater (natural treatment system [wetland and peat bed])	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it minimizes vertical and subsequently horizontal water movement through the tailings as well as the volume of impacted seepage/groundwater that leaves the Tailings Area	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes
Soil cover and vegetation – Divert surface runoff away from the Tailings Area – Collect and treat seepage and groundwater (existing onsite wastewater treatment plant)	Yes – The alternative can contribute to a significant attenuation of any unacceptable impacts to human health and the environment as it minimizes vertical and subsequently horizontal water movement through the tailings as well as the volume of impacted seepage/groundwater that leaves the Tailings Area	Yes – The alternative is likely to conform to government regulations and guidelines	Yes – The alternative has the potential to satisfy design criteria	Yes

For each of the listed alternatives, stormwater runoff that is uncontaminated will be diverted around the Tailings Area to reduce the hydraulic loading to it. Also, in the case of stormwater that percolates through the final cover material, if Young's Creek low-level contaminated sediment is not used as part of the cover material, water collected in the sand layer will be diverted around the Tailings Area. If low-level contaminated sediments are used, the water quality will be monitored and treated, as required.

Cover the Surface of the Tailings Area with Soil and Vegetation

This comprehensive remediation alternative consists of placing soil and seeding and/or planting vegetation across the tailings surface to decrease current precipitation infiltration rates into the tailings, which itself translates into decreased seepage from the tailings, decreased groundwater impacts and, ultimately, decreased loading of contaminants to Young's Creek and the Moira River. As indicated previously, such covers typically consist of multiple layers of soil of varying grain-sizes (clays to sands). They are combined in such a way that water that infiltrates into the topsoil does not migrate through the cover because of the presence of a compacted clay layer at the interface of the material. A typical design would consist of 15 to 30 cm of topsoil, 0.5 to 1.5 m of soil high in organic material (containing compost, wood chips, etc.), a 15 to 30 cm sand layer, and then low permeability soil of 30 to 90 cm. A geotextile would separate the clay layer from the limestone layer to prevent clay from migrating into the crushed limestone. The combination of these layers and depth of each is site-specific and depends on factors such as slope, weather conditions, and level of protection required. At the Tailings Area, the cover would be constructed over the existing nominal 0.6 m of limestone that cover the existing tailings. In this fashion, the primary protection against infiltration during spring thaw, high intensity storms, and wet seasons is the compacted clay layer located immediately above the existing limestone cover.

During the growing season of each year, the majority of the infiltrated water is stored in the topsoil and is evapotranspirated by the vegetation, augmenting the flow barrier provided by the clay layer**.** Due to the clay layer, if the soil exceeds its water holding capacity, excess water will tend to run off the site or drain laterally through the sand drainage layer. In this remediation alternative, the depth of soil cover acts as a water storage layer, which retains water until it can be evapotranspired through the soil surface and the vegetation. This specific design is advantageous in that it minimizes the quantity of high quality clay required, since clay is not available in the immediate vicinity of the site, while making use of locally available and lower-cost materials. It also enhances the productivity of the site for future potential use as wilderness forest.

An option that is being considered for the Tailings Area is the use of the low-impacted material that will be excavated from Young's Creek. This material may be of sufficient quality to allow it to be used as the barrier (clay) layer if it can be compacted to provide a permeability of less than 10^{-7} m/s, or it may be suitable to be mixed with organic materials to become a major part of the highly organic soil (silty clay loam) layer. The cost impact will be a savings of several million dollars. Further investigation of this option is required.

The choice of vegetation cover can consist either of a perennial grass mixture that can be sown into the topsoil layer or a more complex vegetation community consisting of a poplar tree plantation. The function of the vegetation cover is to provide additional water reduction throughout the surface of the tailings cap through evapotranspiration, in addition to that

provided by the low permeability clay and the sand drainage layer. The deeper rooting vegetation increases evapotranspiration from the soil cover and is therefore more desirable.

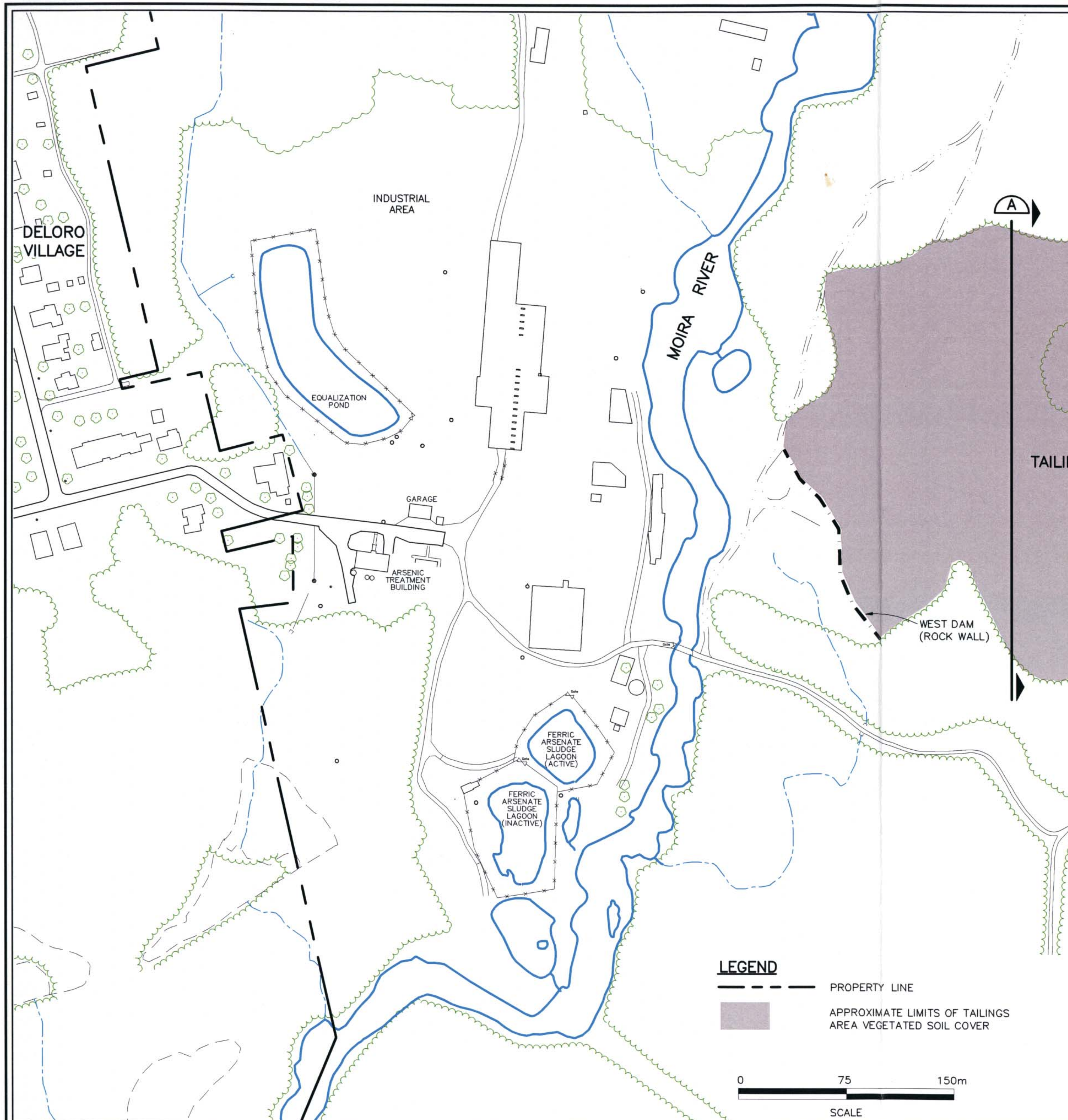
As presented in Section 3.6.4, the Tailings Area constitutes the single largest source of cobalt loading on the Deloro mine property and, as such, should be the major focus of cobalt load reduction for the mine site. To satisfy the PWQO of 0.0009 mg/L for cobalt at the intersection of Young's Creek and the Moira River at Highway 7, the target sitewide loading reduction for the Deloro Mine Site was established at 80 percent, as detailed in the report titled *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (CH2M HILL, May 2002). To achieve this target, upwards of 100 percent reduction would be needed from the Tailings Area plus further reductions from other parts of the site.

Although this comprehensive remediation alternative is expected to significantly reduce contaminant loads to Young's Creek and the Moira River, this alternative, in the absence of additional cobalt load reduction measures (e.g. surface water runoff diversion or seepage and groundwater treatment) will likely not satisfy the targeted cobalt load reductions at the intersection of these watercourses and Highway 7. This has been determined from results of modelling exercises provided in the report titled *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (CH2M HILL, May 2002), which indicate that, as a function of the design of a vegetated soil cover, reduction of surface water run-on is an additional measure that will be required to satisfy the cobalt reduction target. Figures 5-1 and 5-2 show a conceptual plan and cross-section of a typical engineered, vegetated, soil cover.

Cover the Surface of the Tailings Area with Soil and Vegetation and Divert Surface Runoff Away from the Tailings Area

This comprehensive remediation alternative combines the soil cover and vegetation alternative described above and the environmental protection feature identified in Table 5.1 of diversion of surface runoff away from the Tailings Area. SRK (1998) reported that an interceptor ditch could be constructed along the east side of the tailings to reduce run-on from approximately 4.3 ha of the 16.1 ha that constitute the catchment area in the vicinity of the Tailings Area. Such a ditch would reduce surface water run-on and infiltration into the existing limestone cover of the tailings by approximately 27 percent. This approach assumed the interceptor ditch was to be constructed within the existing limestone and tailings surface. However, if a soil cover of more than 1-m thick is added to the surface of the tailings, there is potential for diverting more than 90 percent of the run-on water away from the Tailings Area surface. Added infiltration reduction by run-on may be possible by collecting the remaining run-on in swales that would transport the stormwater across the surface of the tailings cover reducing the retention time of this water on the surface.

Results of modelling work performed by CH2M HILL in the *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (CH2M HILL, May 2002) suggest that, when an engineered soil cover vegetated with poplar trees is combined with an interceptor ditch, the reduction of water infiltration into the tailings could reach up to 93 percent after the poplars reach maturity (which is expected to take four to seven years). Under the assumption that metal contaminant loadings are directly proportional to water infiltration, the combination of an engineered soil cover, vegetated with poplar trees and an interceptor ditch could lead to cobalt loading reduction of up to 93 percent. It is expected that, with



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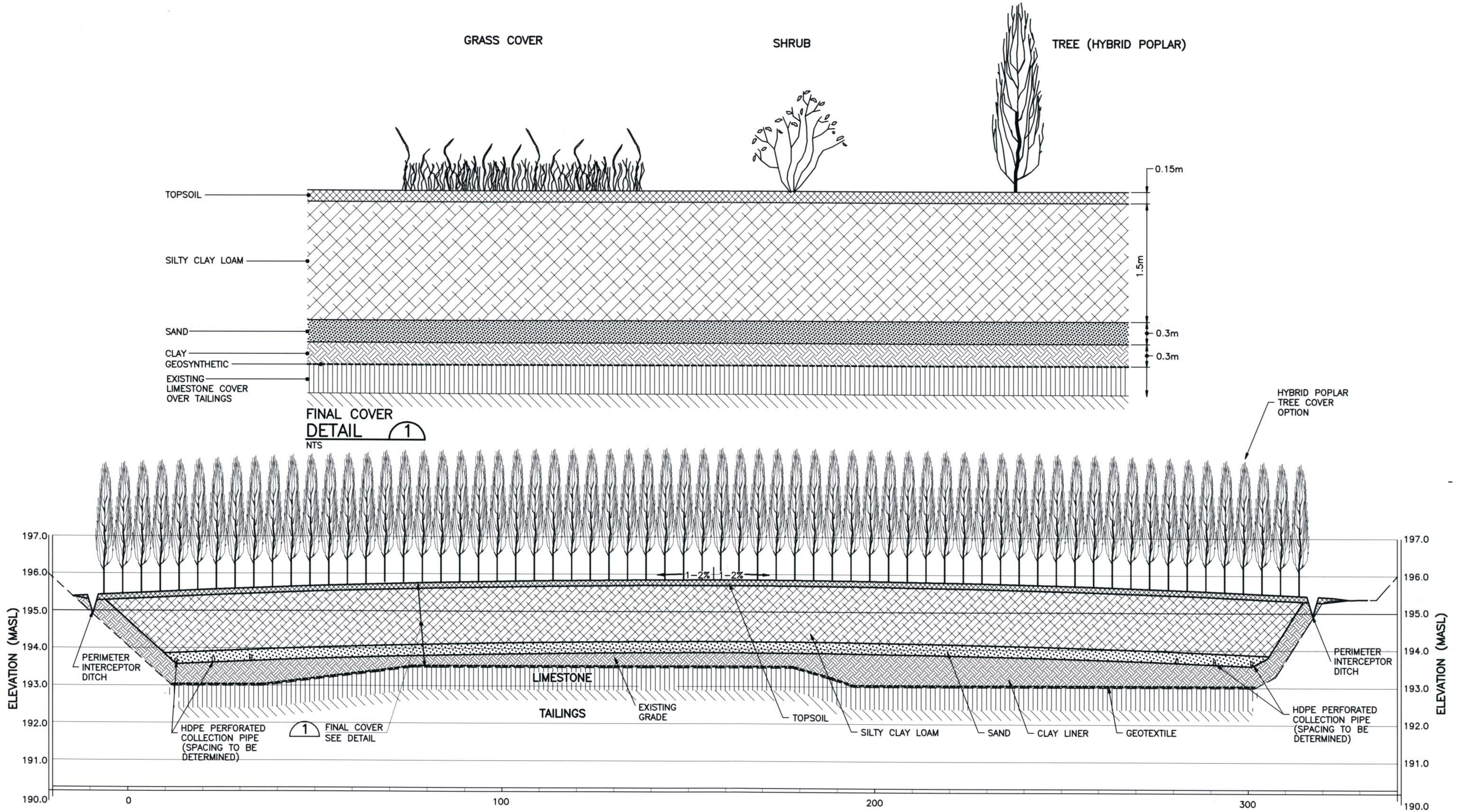
REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-1
CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER

27/MAY/2002



ENGINEERED SOIL COVER AND HYBRID POPLAR PLANTATION
SECTION A–A
10X VERTICAL EXAGERATION
A FIG.5–1

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FIGURE 5-2
CONCEPTUAL CROSS-SECTION OF THE PROPOSED VEGETATED SOIL COVER

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such a reduction in cobalt loading from the Tailings Area, combined with load reduction measures from the Industrial and Mine Areas , the PWQO for cobalt may be satisfied at the intersection of the Moira River and Young's Creek with Highway 7. Figures 5-3 and 5-4 show a plan view of the approximate location of the proposed vegetated soil cover and interceptor and a cross-section of the latter, respectively.

Cover the Surface of the Tailings Area with Soil and Vegetation, and Collect and Treat Seepage and Groundwater Using a Natural Treatment System

This comprehensive remediation alternative combines the engineered vegetated soil cover and the collection and treatment of seepage and groundwater from the tailings. In this alternative, seepage that escapes the Tailings Area through the east and west tailings dams and groundwater that flows through the fractured bedrock on which the dams were built are collected by a series of sumps/wells that are excavated/drilled in the vicinity of the dams. In this alternative, seepage and groundwater are directed to two natural treatment systems (each located downstream of the eastern and western dams) that are made up of three main components (i.e. an anoxic limestone drain followed by a peat bed and a constructed wetland). Surface water runoff would not be in contact with contaminated soils and would, therefore, be diverted around the treatment system. Figure 5-5 illustrates a conceptual plan of the eastern and western natural treatment systems that would be constructed in the vicinity of the eastern and western tailings dams. Figure 5-6 shows conceptual cross-sections of these constructed natural treatment systems.

The expected performance of this comprehensive remediation alternative in terms of reducing cobalt loads to the Moira River and to Young's Creek is such that the PWQO for cobalt will likely be satisfied at the intersection of these water courses and Highway 7, since the alternative combines two means to reduce cobalt loading (i.e. minimizing infiltration and natural water treatment).

By constructing a natural treatment system at the same time as the installation of the soil and vegetation cover, tailings seepage can be controlled from the outset and through the interim period, until the poplar tree cover becomes fully mature. This option, therefore, requires further consideration. The main issue to consider in this alternative is whether it is preferable to determine if a natural treatment system is necessary in the future, or whether a natural treatment system should be considered from the outset. The reduction in infiltration along the surface from soil addition and vegetation uptake may also reduce contaminant loadings to acceptable levels. The added advantage of collecting and treating seepage and groundwater is its value as a contingency, in the event that seepage and groundwater flows cannot be adequately controlled due to unusually wet periods or unforeseen circumstances. Seepage flows from the Tailings Area can be monitored for several years after the poplar trees become established to determine if additional collection and treatment is necessary.

Cover the Surface of the Tailings Area with Soil and Vegetation, and Collect and Treat Seepage and Groundwater at the Existing Wastewater Treatment Plant

The fundamental features of this comprehensive remediation alternative are identical to the previous option. However, in this case, collected seepage and groundwater are directed to the equalization pond located on the west side of the Moira River in the Industrial Area through an insulated and heat traced pipe. Seepage and groundwater would therefore

simply be treated along with the groundwater pumped from the Industrial Area and the Main Mine Area of the Deloro Mine Site. The expected performance of this comprehensive remediation alternative in terms of cobalt load reduction to Young's Creek and the Moira River is similar to the remediation alternative described above. Under this scenario, it is assumed that the additional volume of water pumped from the Tailings Area to the equalization pond is relatively small (approximately 1,300 m^3 /yr) and that the wastewater treatment plant can adequately remove dissolved cobalt from the raw water. The limited data that is available from testing done by the wastewater treatment plant staff suggests that removal efficiencies for cobalt may be as high as 73 percent. Figure 5-7 illustrates a potential layout of the system required to collect seepage and groundwater and to pipe them to the equalization pond.

Cover the Surface of the Tailings Area with Soil and Vegetation, Divert Surface Runoff Away from the Tailings Area, and Collect and Treat Seepage and Groundwater Using a Natural Treatment System

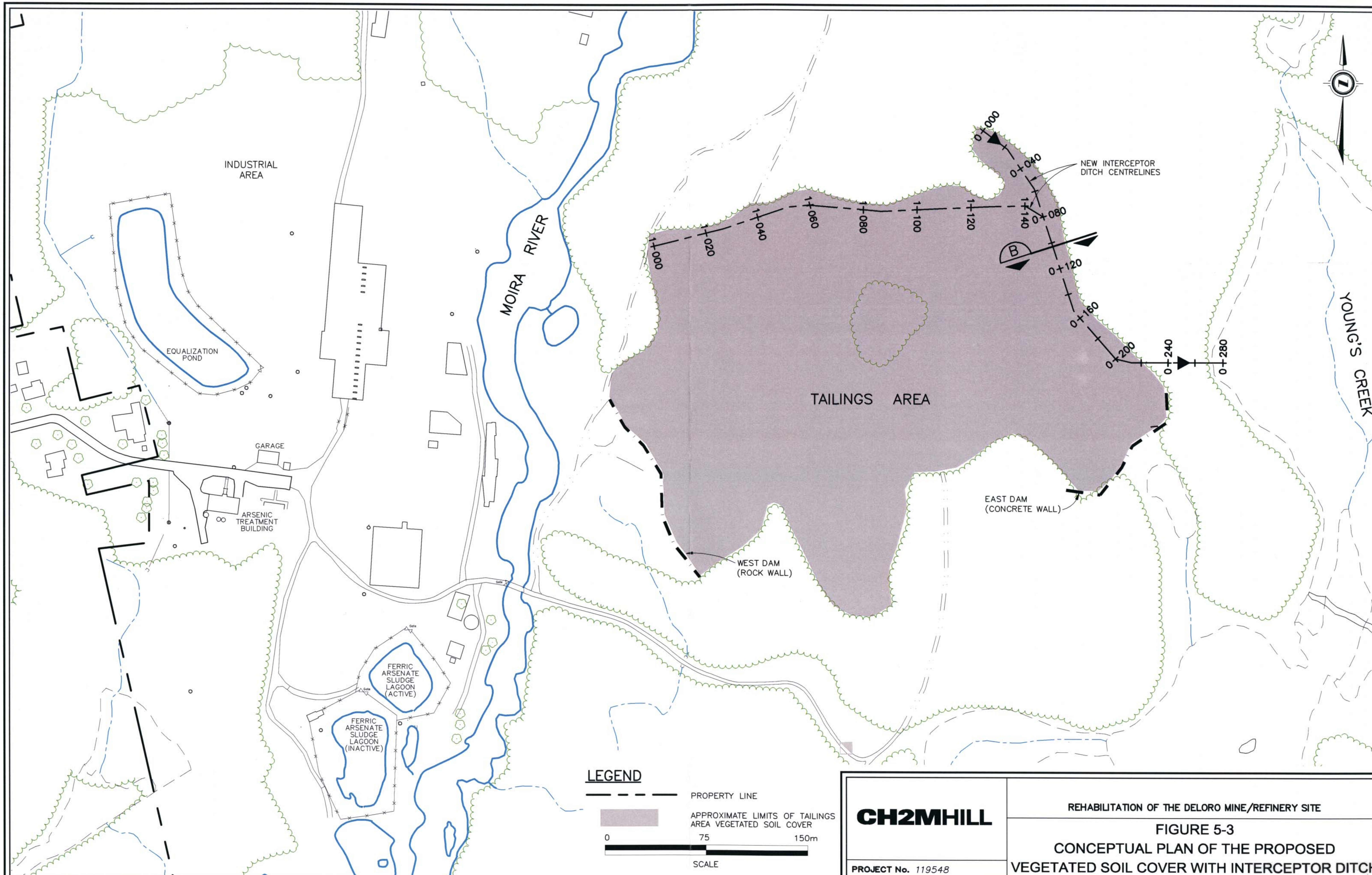
This comprehensive remediation alternative combines the engineered vegetated soil cover, the interceptor ditch to divert surface water run-on from part of the lands adjacent to the eastern portion of the tailings and the collection and treatment of seepage and groundwater from the tailings as described above. In this alternative, collected seepage and groundwater are directed to a natural treatment system as described earlier.

The expected performance of this comprehensive remediation alternative in terms of reducing cobalt loads to the Moira River and to Young's Creek in such a way that the cobalt PWQO will be satisfied at the intersection of these water courses and Highway 7 is very good as the alternative combines three features to control contaminant release and migration. Figure 5-8 shows a conceptual plan view of this alternative, while Figures 5-2, 5-4, and 5-6 illustrate the cross-sections of the main components of this alternative.

Cover the Surface of the Tailings Area with Soil and Vegetation, Divert Surface Runoff Away from the Tailings Area, and Collect and Treat Seepage and Groundwater at the Existing Wastewater Treatment Plant

The fundamental features of this last comprehensive remediation alternative are identical to the previous option. However, in this case, collected seepage and groundwater are directed to the equalization pond located on the west side of the Moira River in the Industrial Area through an insulated and heat traced pipe. Seepage and groundwater would therefore simply be treated along with the groundwater pumped from the Industrial Area and the Main Mine Area of the Deloro Mine Site. The expected performance of this comprehensive remediation alternative in terms of cobalt load reduction to Young's Creek and the Moira River is similar to the remediation alternative described above, that is because the alternative combines three features to control contaminant release and migration. Figure 5-9 illustrates a conceptual plan view of the potential layout of this alternative and Figures 5-2 and 5-4 show the relevant cross-sections of the main components of this alternative.

Each short-listed comprehensive remediation alternative is evaluated in the following section.



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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-3
CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER WITH INTERCEPTOR DITCH

PROJECT No. 119548

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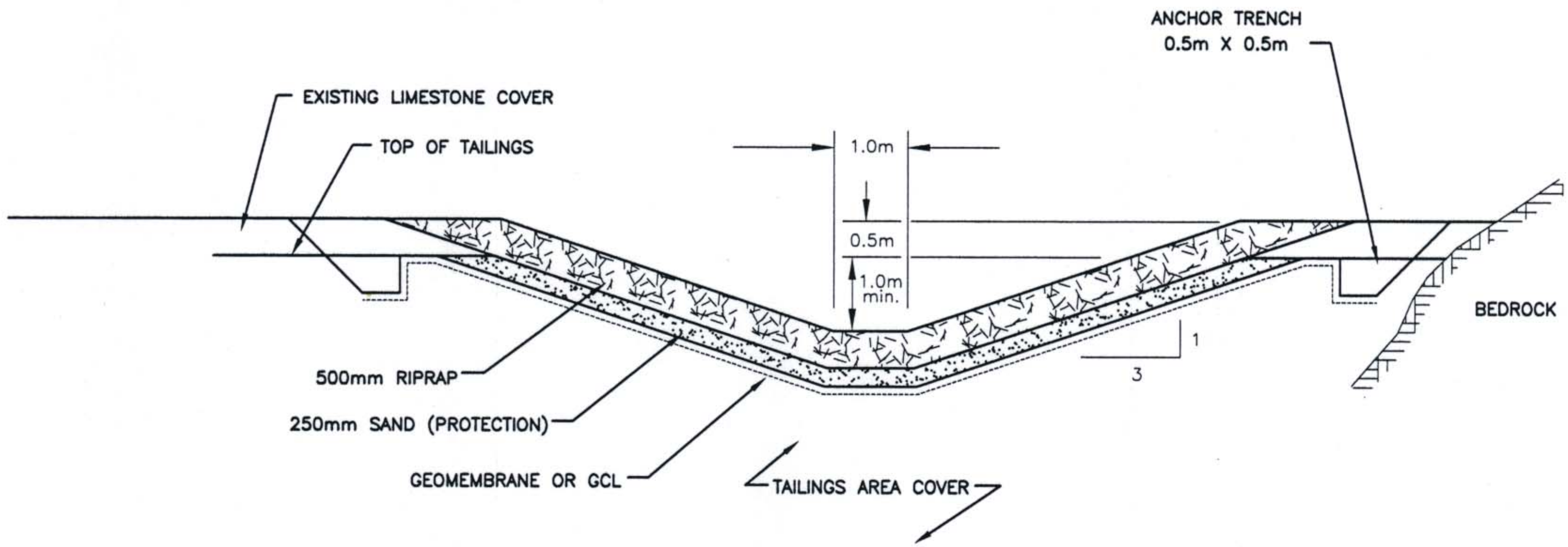

TYPICAL SECTION
SECTION B–B

B
FIG.5–3

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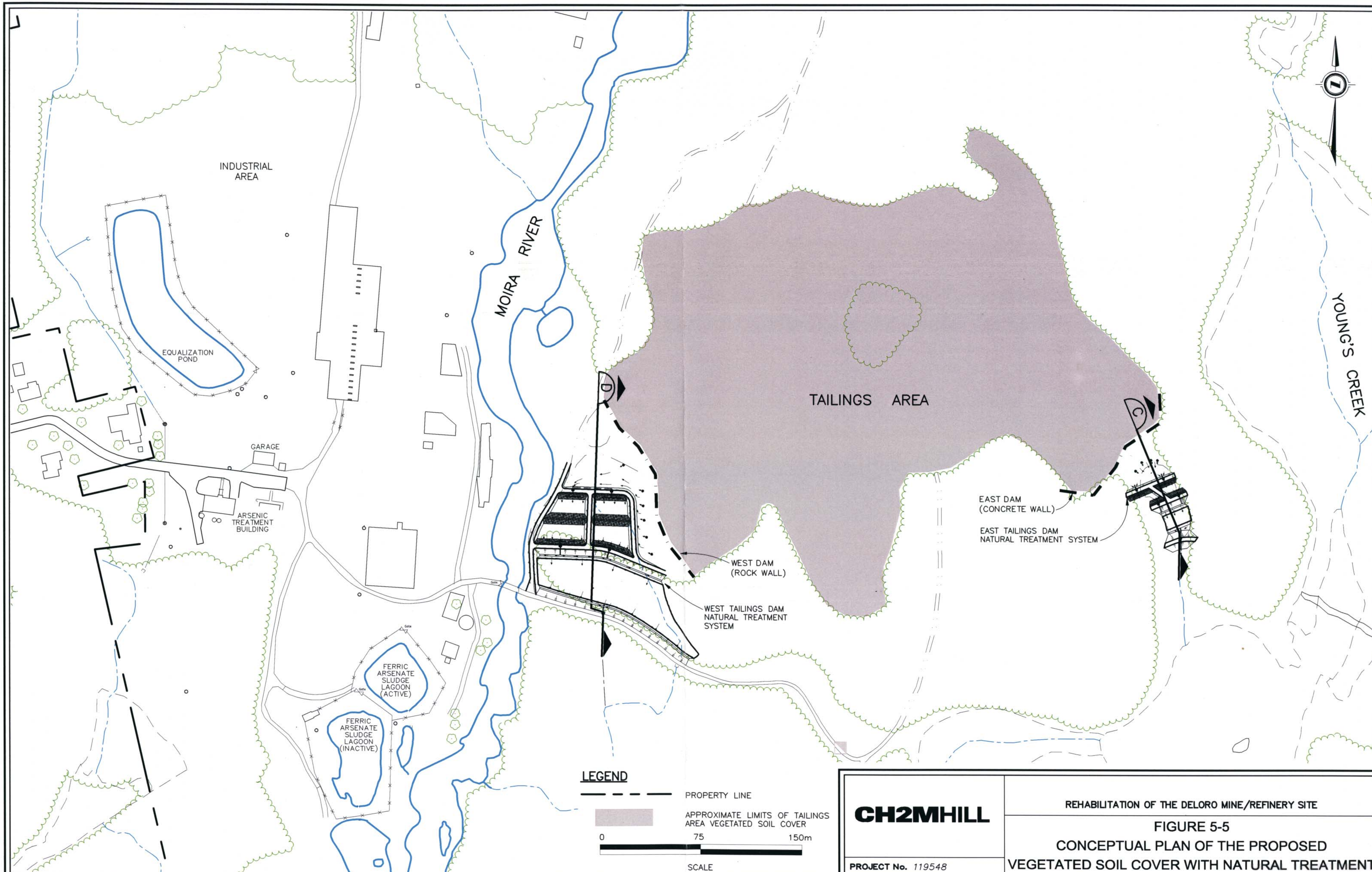
REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-4
INTERCEPTOR DITCH CROSS-SECTION



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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-5
CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER WITH NATURAL TREATMENT

PROJECT No. 119548

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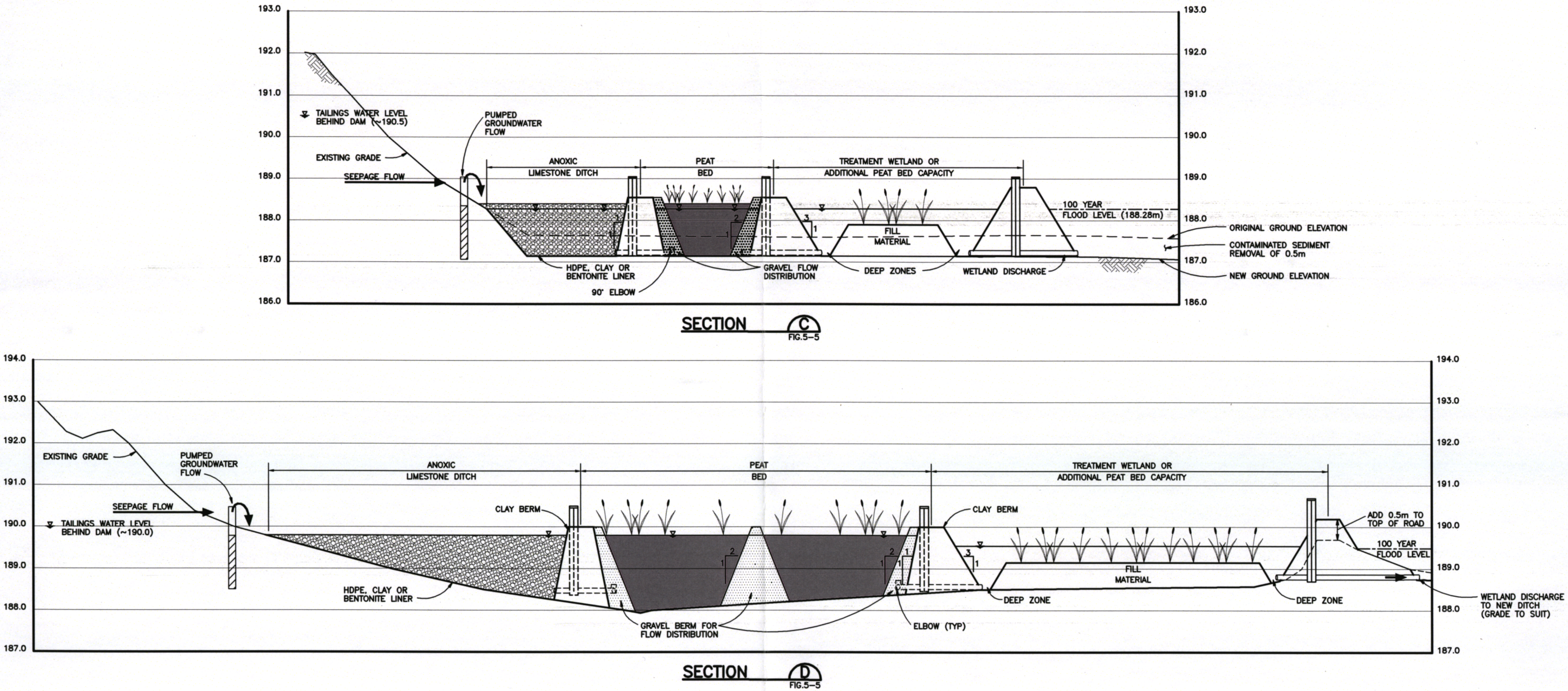
28/MAY/2003



0 10 20m
SCALE

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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-6
NATURAL TREATMENT SYSTEM
CONCEPTUAL CROSS-SECTIONS C AND D (TYPICAL)

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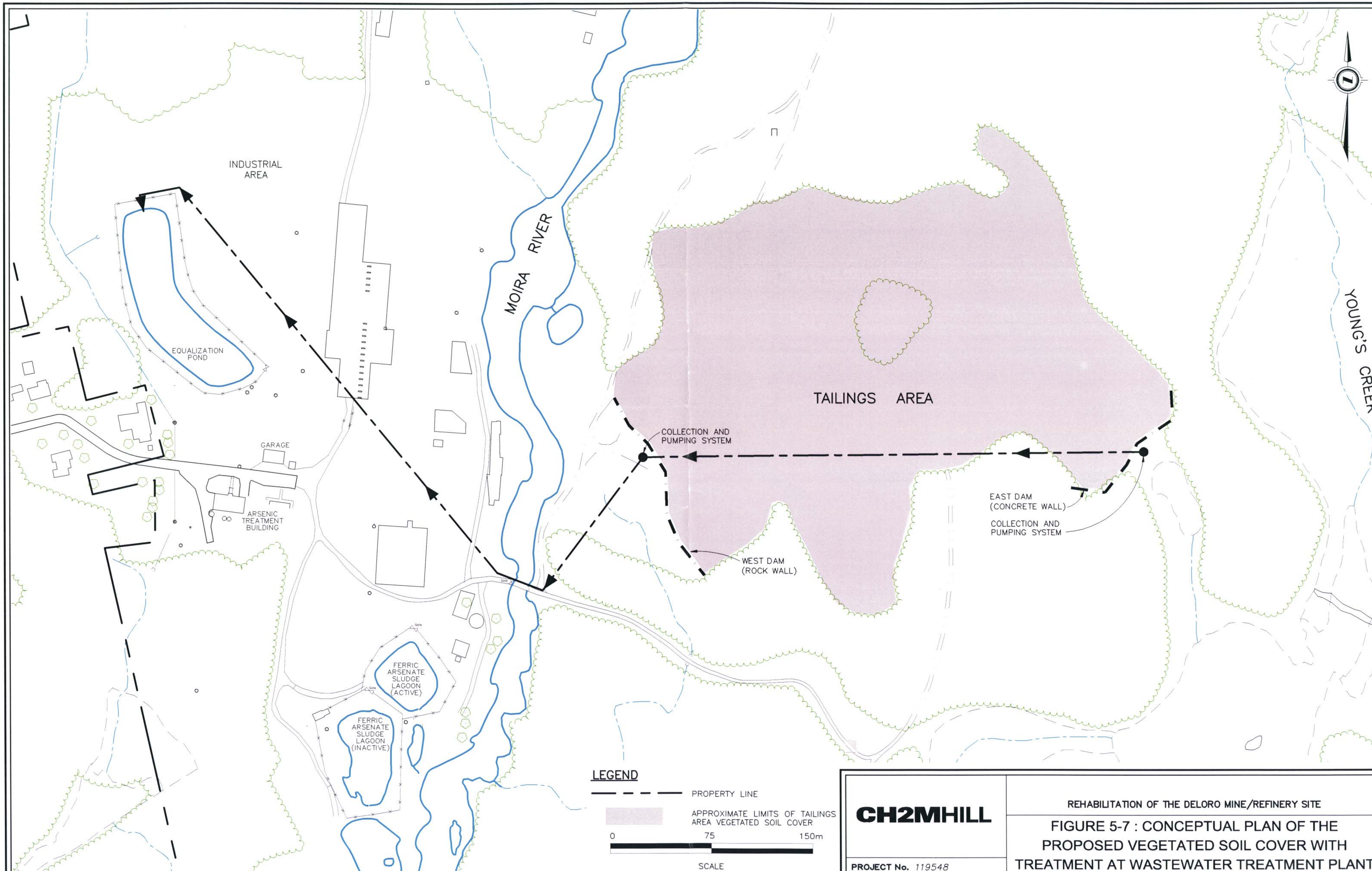

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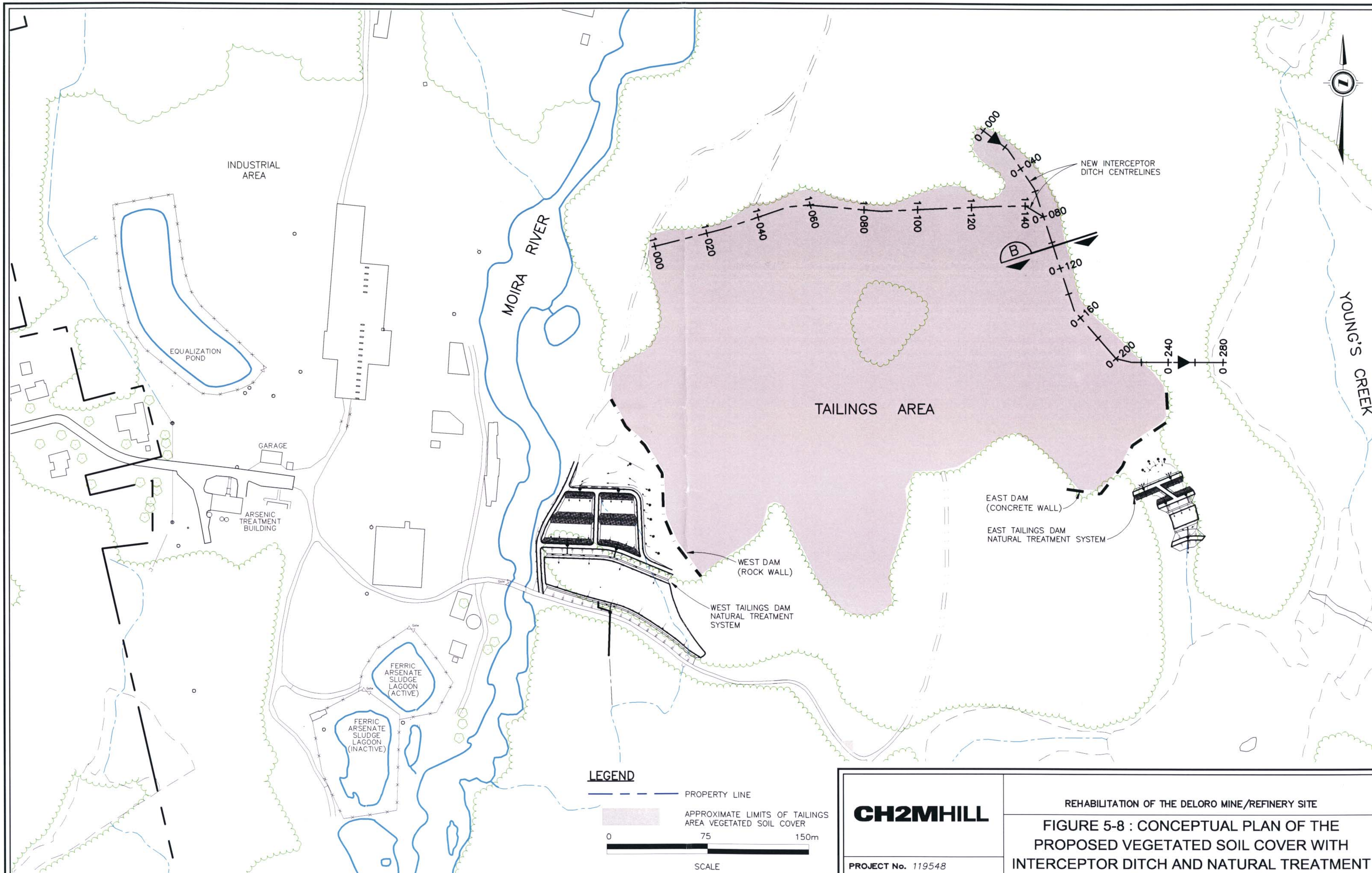
REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-7 : CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER WITH TREATMENT AT WASTEWATER TREATMENT PLANT

PROJECT No. 119548

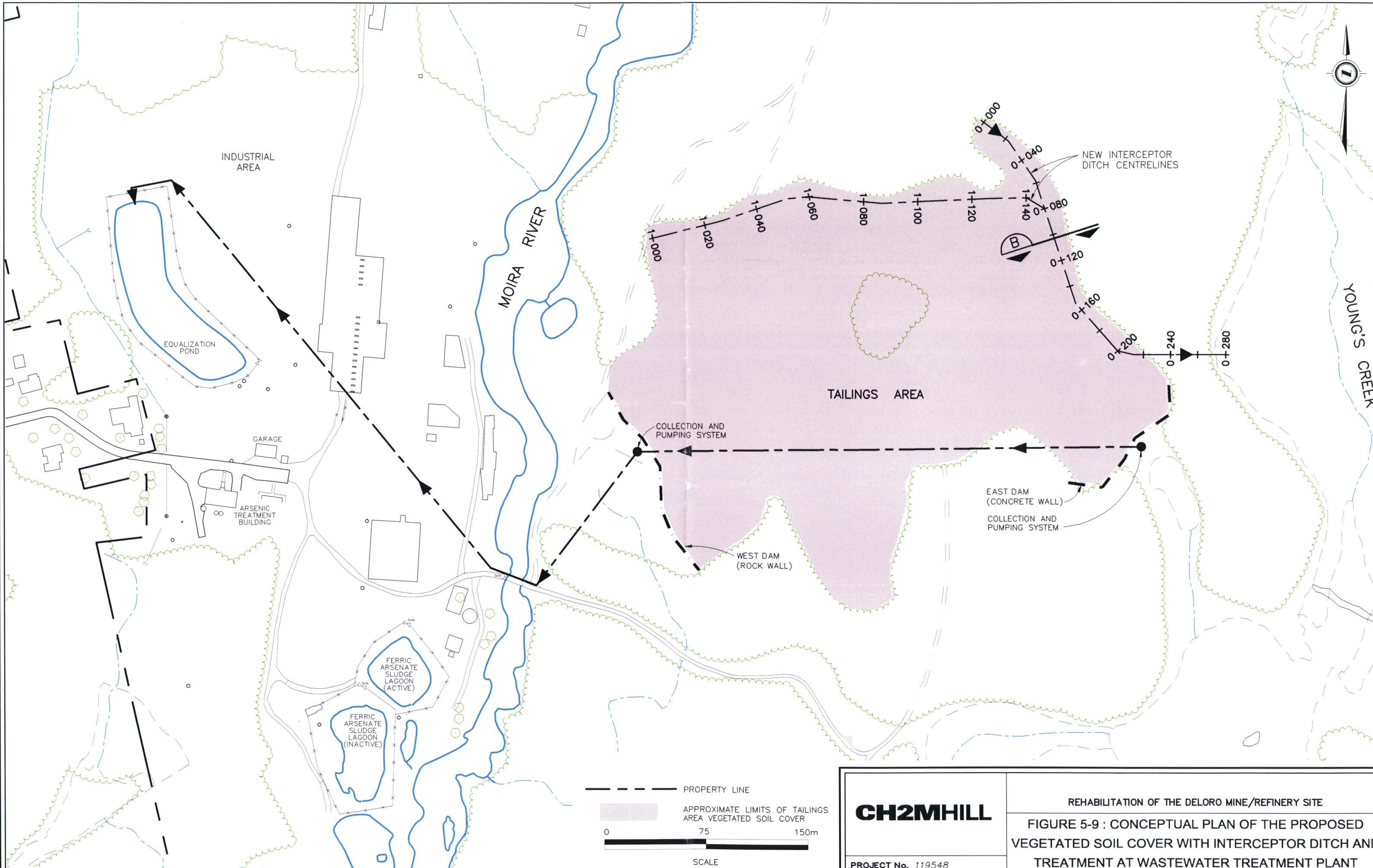


CH2MHILL

REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-8 : CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER WITH INTERCEPTOR DITCH AND NATURAL TREATMENT

PROJECT No. 119548



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REHABILITATION OF THE DELORO MINE/REFINERY SITE

FIGURE 5-9 : CONCEPTUAL PLAN OF THE PROPOSED VEGETATED SOIL COVER WITH INTERCEPTOR DITCH AND TREATMENT AT WASTEWATER TREATMENT PLANT

PROJECT No. 119548

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5.4 Detailed Evaluation of Short-Listed Alternatives

As explained in Section 4.5, the six identified short-listed alternatives were compared to a set of detailed evaluation criteria that are designed to select a recommended remediation alternative. Table 5.3 summarizes the results of the evaluation process while details are provided below.

5.4.1 Technical Considerations

Reliability

This criterion evaluates the ability of the alternative to satisfactorily control discharge of cobalt to the Moira River and Young's Creek basins. With the exception of the soil cover and vegetation (only) alternative, all alternatives are evaluated to satisfactorily control discharge of cobalt to the environment as they combine at least two control features to minimize contaminant loading to the environment. The reliability of the alternatives increase with the number of environmental protection features added on to the primary remediation method as well as with the capacity of the alternative to decrease the input water into the tailings. It should be noted that although the Tailings Area was identified as the main contributor of cobalt to the environment, full achievement of the PWQO for cobalt at the intersection of the Moira River and Young's Creek and Highway 7 will require controlling cobalt releases from other portions of the Deloro Mine Site as well.

Compatibility with Existing System

All short-listed comprehensive remediation alternatives are estimated to be compatible with existing site conditions. However, all alternatives will require an investigation of the structural integrity of the east and west tailings dams, not only to determine their ability to contain the tailings in the long term but also to determine their ability to contain the added weight of the soil cover and associated vegetation and construction equipment. Similarly, the ability of the tailings to support construction equipment may require modified techniques. Costs associated with dam repairs are not possible to estimate at this point because they are dependent upon an inspection that is yet to be completed. Likewise, the ability of the existing wastewater treatment plant to receive and successfully treat approximately 1,300 m^3 of seepage and groundwater annually from the Tailings Area must be investigated.

Ease of Implementation

The construction of a soil cover over the surface of the tailings will require significant efforts in terms of importing aggregates and soil to the mine site and grading these materials to construct the engineered cover. Here, again, the ability of the tailings to support construction equipment may require modified techniques. In the event that hybrid poplar tree technology is selected to promote evapotranspiration from the cover and to consequently minimize water infiltration into the tailings, it is estimated that a period of four to seven years will be required for the poplars to reach a size large enough to evapotranspirate significant volumes of water stored in the engineered cover (CH2M HILL, May 2002). During the period of growth and maturation of the plantation, the cap will rely on the clay barrier to reduce infiltration and divert stormwater runoff from the tailings.

Since some level of infiltration into the tailings will continue for that period of time, a large enough system will be required to treat seepage and groundwater from the Tailings Area for approximately four to seven years. The diversion ditch (i.e. interceptor) construction is anticipated to be carried out in the top metre of the newly constructed cover and is not expected to be a construction challenge. It is anticipated that the construction of two "natural treatment systems" (one on the east and one on the west sides of the Tailings Area), as described earlier, will require greater effort and expenditures to implement than the construction of a collection and pumping system from the Tailings Area to the equalization pond for the wastewater treatment plant.

5.4.2 Costs

The capital and construction costs, the annual operation and maintenance costs, and the net present value costs associated with each alternative are summarized in Table 5.3. The breakdown of various components of the total cost associated with each alternative is detailed in Appendix B. In addition, the major assumptions used in the cost opinions are also stated in that appendix. Because of the uncertainty in design requirements at this conceptual design stage, all costs provided should be considered as "cost opinions" at this stage to assist the MOE in choosing among comprehensive remediation alternatives.

The capital costs associated with the construction of the six comprehensive remediation alternatives varies from $6,644,300 for a vegetated (hybrid poplar trees) engineered soil cover to $9,205,900 for the same vegetated engineered soil cover combined with diversion of surface water runoff and a natural treatment system as described in Section 5.3. Annual operation and maintenance costs for these alternatives range from $130,100 to $242,100 and the net present value of these annual operation and maintenance costs range from $1,702,600 to $3,168,400. Operation and maintenance costs are typically higher for the natural treatment technology option ($112,000) than for the collection and pumping option which directs seepage and groundwater to the existing wastewater treatment plant ($9,600).

The net present value calculations were based on an assumed effective interest rate of five percent and a planning horizon of 20 years. The 20-year period was selected based on the assumption that it is a reasonable period for budgetary planning purposes.

5.4.3 Social Considerations

Public Acceptance

All comprehensive remediation alternatives are likely to receive a reasonable degree of public acceptance as the proposed alternatives deal with onsite containment of the tailings materials, minimal (if any) handling of the tailings materials and significant reduction of contaminant loads to the environment. Furthermore, the general appearance of the Tailings Area will be significantly improved when compared to the current state of the Area. The use of a tree rather than a grass cover will more closely reflect the current surrounding environment and may be seen as more acceptable by the public.

TABLE 5.3
EVALUATION OF SHORT-LISTED COMPREHENSIVE REMEDIATION ALTERNATIVES

Short-Listed Comprehensive Remediation Alternatives	Detailed Evaluation Criteria															
	Technical Considerations			Costs[2]			Social Considerations						Natural Environment			
	Reliability	Compatibility with Existing System	Ease of Implementation	Annual O&M Costs	Capital Costs (millions)	Capital and O&M Net Present Value Costs[1] (millions)	Public Acceptance (Level of Reservation)	Risk to Public	Constraint for Recreational Use	Negative Impact to Private Properties	Visual Character (Impact)	Risk to Workers (Health and Safety)	Geochemistry (Improvement)	Terrestrial Habitats (Improvement)	Floodplain (Infringement)	Fish Habitats (Disruption)
1. Soil cover and vegetation	Fair	Good	Good	$130,100	$4.94	$6.64	Low	Low	Low	Low	Low	Low	High	Good	Low	Low
2. Soil cover and vegetation – Diversion of surface runoff	Good	Good	Good	$130,100	$5.14	$6.85	Low	Low	Low	Low	Low	Low	High	Good	Low	Low
3. Soil cover and vegetation – Collection and treatment of seepage and groundwater (natural treatment system)	Good	Good	Fair	$242,100	$5.84	$9.00	Low	Low	Low	Low	Low	Low	High	Good	Moderate	Low
4. Soil cover and vegetation – Collection and treatment of seepage and groundwater (wastewater treatment plant)	Good	Good	Good	$139,700 (assumes no additional chemical costs or operator effort)	$5.06 (assumes no upgrade required)	$6.89	Low	Low	Low	Low	Low	Low	High	Good	Low	Low
5. Soil cover and vegetation – Diversion of surface runoff – Collection and treatment of seepage and groundwater (natural treatment system)	Good	Good	Fair	$242,100	$6.04	$9.21	Low	Low	Low	Low	Low	Low	High	Good	Moderate	Low
6. Soil cover and vegetation – Diversion of surface runoff – Collection and treatment of seepage and groundwater (wastewater treatment plant)	Good	Good	Good	$139,700 (assumes no additional chemical costs or operator effort)	$5.27 (assumes no upgrade required)	$7.09	Low	Low	Low	Low	Low	Low	High	Good	Low	Low

1 Net present value costs assumed an effective interest rate of 5% and a time horizon of 20 years.

2 Costs include GST and a 15% contingency (before taxes, overhead, insurance, and bonds)

Expected cost accuracy is +50/-30%.

See Appendix B for more detailed cost breakdown including overhead, insurance, and bonds cost estimates.

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Risk to Public

Because all comprehensive remediation alternatives involve little handling of contaminants and the Deloro Mine Site is effectively restricted to public access, the risk to public health and safety is estimated to be low for all alternatives.

Constraint for Recreational Use

The potential for all of the comprehensive remediation alternatives to have an impact on recreational activities is low as the Deloro Mine Site is not accessible to the public. Regardless, should that condition change in the years to come, the tailings materials will effectively be isolated by an engineered vegetated soil cover and will consequently not be accessible to the public. The root system of a tree cover will reduce potential for access to the tailings even further. In the event that the natural treatment technology should be selected to treat seepage and impacted groundwater from the tailings, consideration should be given to restricting access to the treatment wetlands.

Negative Impact to Private Properties

All comprehensive remediation alternatives are anticipated to have minimal impact on private properties as the Tailings Area is located in the central portion of the Deloro Mine Site. As it is anticipated that a large volume of soil and aggregates will be brought onsite, measures will have to be implemented to minimize disturbances caused by vehicular traffic (e.g. trucking hours, use of tarps on trucks to minimize dust generation, truck washing station at the exit of the site, sweeping the road used by trucks to haul aggregates, as required, and compliance with municipal by-laws governing noise and construction site activity times). Primary access to the Tailings Area will be via the Highway 7 access road, thereby limiting vehicular traffic in the Village of Deloro.

Visual Character of the Area

All of the comprehensive remediation alternatives will result in a significant improvement to the visual character of the Tailings Area, as a vegetated soil cover will cover the crushed limestone. Again, a tree cover will be more in keeping with the adjacent forested areas.

Risk to Workers

As most of the work in the Tailings Area will involve the transportation and grading of earthen materials and little, if any, handling of tailing material, the health and safety risk to workers is expected to be low (i.e. similar to the risks associated with large earth moving works, such as heavy machinery hazards).

5.4.4 Natural Environment

Geochemistry

Because all comprehensive remediation alternatives either minimize infiltration of surface water into the tailings or minimize both the infiltration of surface water and the release of impacted water to the Moira River and Young's Creek, they are all anticipated to significantly improve the quality of surface water emanating from the Tailings Area.

Terrestrial Habitats

The current state of the terrestrial habitat in the Tailings Area can be described as poor given that the surface of the tailings is covered by crushed limestone. Consequently, all of the alternatives considered will result in a significant improvement to terrestrial habitats of the Tailings Area by the implementation of a vegetated engineered soil cover.

Floodplain

With the exception of the two comprehensive remediation alternatives that incorporate the use of "natural treatment systems" to treat seepage and groundwater, work conducted in the Tailings Area will not infringe upon the floodplain. In the case of the two alternatives that include the natural treatment system, disruption of the floodplain will be minimal. Diversion of surface water may lead to increased peak flows in the floodplain although this is not anticipated to alter the floodlines to any great extent.

Fish Habitats

As none of the comprehensive remediation alternatives involve work in a watercourse, the potential of the alternatives to impact fish habitats adjacent to or downstream of the Tailings Area is minimal. However, runoff and sediment control measures will need to be implemented during the construction of the selected remediation alternative for the Tailings Area.

5.4.5 Selection of Recommended Remediation Alternative

In light of the information presented above, one factor stands out as contributing the most to the reduction of cobalt loading to the environment. It is the reduction of water contact with the tailings through runoff and infiltration. Based on that factor, the comprehensive remediation alternative that is expected to be most effective in reducing infiltration and mitigating discharge from the Tailings Area consists of the following:

- Cover the surface of the Tailings Area with soil and vegetation
- Divert surface runoff away from the Tailings Area
- Collect and treat seepage and groundwater from the Tailings Area at the existing Wastewater Treatment Plant

Vegetation

In general, the use of a grass cover may be viewed as the simplest form of vegetation cover that can provide water reduction through evapotranspiration. However, the CH2M HILL final report *Feasibility Study for a Combined Soil Cover and Poplar Tree Cap in the Tailings Area* (May 2002) suggests that the use of a poplar tree technology system may be a more effective alternative for providing water infiltration reduction. While a grassed cover can provide surface soil stability for a gradual (less than 2:1) sideslope, the rooting depth of grasses tends to be limited to the top 15 to 30 cm. This results in grasses extracting water to that depth, but inability to pursue the deep percolation water. Grass covers typically have a shorter growing season than trees, during which time the cover is actively evapotranspiring. The surrounding trees will reduce the evaporative effects from the soils and from the leaves since they will tend to block wind flow, reducing the grass cover's rate of evapotranspiration. However, a tree cover will quickly grow to the height of surrounding

trees and expose the leaf surfaces to greater wind influence. As a result, the volume of water that would be evapotranspired over the course of a year is expected to be greater for a tree plantation. During the final design stage, an assessment that considers the availability and costs of various vegetative materials will need to be carried out. Due to the higher level of predicted performance of a poplar tree plantation, further background information is presented below.

The poplar tree alternative consists of a dense stand or plantation of poplar trees, grass cover, and an associated soil support system (growing medium), which can collect, store, and consume natural precipitation at the site. The use of hybrid poplar clones was first developed to address the pulp and paper industry's requirements for uniform raw material and higher biomass production (CH2M HILL, May 2002). Research on cloning has produced hybrids that are tolerant of a wide range of conditions that would inhibit tree establishment and growth of most other tree species.

Clone development generated an interest in the application of poplars for water management and site remediation. The MOE has funded studies on the use of poplar plantations for land application and management of landfill leachate (Shrive et al., 1994). Recent studies have shown that the combined precipitation and irrigation requirements of a four-year-old poplar stand can exceed 1,500 mm over a growing season (Cuenca and Kelly, 1998). This is greater than the total annual precipitation for locations in Ontario. Therefore, poplar tree systems can be designed and managed to reduce or effectively eliminate deep percolation of precipitation and irrigated wastewater.

The feasibility study for the use of a combined soil cover and poplar tree cap in the Tailings Area found that a combined soil cover and poplar tree cap above the tailings impoundment can achieve reductions in water flow (deep percolation) that can satisfy the metal contaminant reduction targets for the site (CH2M HILL, May 2002). The full reduction potential is not realized until four to seven years following implementation because of the time it takes for trees to reach maturity.

Soil Cover

The preferred choice of soil cover was examined in the feasibility study by modelling the reduction of deep percolation with different thicknesses of silty clay loam in combination with topsoil, sand, and compacted clay materials (CH2M HILL, May 2002). The topsoil provides the initial rooting medium for the poplar trees, while the silty clay loam and sand provide the necessary water storage capacity that will increase the effectiveness of the poplar trees. The compacted clay layer functions as a restricting layer to minimize percolation of water into the underlying limestone cover and tailings (red mud). Based on the findings of the feasibility study, the construction of a soil cover incorporating a 100- or 150-cm silty clay loam in addition to a 15-cm topsoil layer, a 30-cm sand drainage layer, and a 30-cm compacted clay base will be sufficient to achieve deep percolation reductions of 83 to 93 percent above existing conditions if deep rooting vegetation (i.e. poplar trees) is selected. The feasibility study also suggested that percolation reductions to the existing limestone cover can approach 100 percent if the sand layer is constructed to effectively transmit lateral flow away from the Tailings Area (CH2M HILL, May 2002). Note that this design basis requires importing high quality clay and organic materials to produce the silty

clay loam. The design will be optimized based on material availability (this includes considering excavated Young's Creek sediments/soils), costs and performance.

During the implementation of the preferred alternative, there are many factors to consider in the selection of the most suitable materials used, sources of materials, and costs involved in construction, haulage, and raw material. For instance, consideration was initially given to the use of the less contaminated sediments/soils excavated from Young's Creek as building materials for the soil cover. However, uncertainty associated with the long-term effects of potential arsenic uptake by the vegetation of the soil cover made that consideration questionable from a technical standpoint and must be evaluated further to determine if less contaminated soils are a viable option that could reduce project costs.

Interceptor Ditch System

Although the use of a soil and vegetation cover will be effective in reducing the infiltration and deep percolation of water, an interceptor ditch will be required to achieve a greater level of water inflow reduction. The advantages of an interceptor drain are a reduction of the water flow into the Tailings Area and an expected reduction of the influx of contaminants into the Moira River and Young's Creek.

An effective interceptor ditch could be constructed along the east side of the Tailings Area, where a 27 percent reduction in effective catchment area can be achieved and may include a ditch along with north side of the Tailings Area where even further reduction of run-on water may be possible.

Treatment Considerations

Although collection and pumping to the existing wastewater treatment plant or to a natural treatment system consisting of a peat bed and constructed wetland is a feasible approach for further reducing the tailings leachate contaminant loading to the Moira River and Young's Creek (*Natural Treatment Technology Feasibility for Tailings Leachate Contaminant Reduction* [CH2M HILL, March 2002b]), the amount of contaminated seepage that will be produced after installation of the vegetated soil cover and the interceptor ditch is difficult to predict with certainty. The reduction in infiltration from topsoil and vegetation might be adequate to reduce contaminant loading to acceptable levels. The poplar tree feasibility study supports this statement. However, it is anticipated that some level of seepage flows will continue during the initial four to six years of poplar tree plantation establishment, when infiltration rates are expected to be higher (CH2M HILL, March 2002b), but decrease as the poplar plantation matures. Based on these facts, there are two approaches that the MOE could consider in implementing the preferred alternative:

1. Establish a vegetated soil cover on the tailings and monitor its effectiveness to determine if further treatment is necessary.

2. Provide for seepage and groundwater treatment at the same time as the vegetated soil cover installation as a contingency plan assuming that treatment of seepage and groundwater will be necessary.

There are inherent risks and tradeoffs involved in both approaches. The advantages and disadvantages of each approach are listed in Table 5.4.

TABLE 5.4
COMPARISON OF TWO RECOMMENDED APPROACHES OF IMPLEMENTING THE RECOMMENDED ALTERNATIVE

	1. Vegetated Soil Cover	2. Vegetated Soil Cover + Seepage and Groundwater Treatment
Advantages	• Less capital costs • Less O & M costs • Passive approach • Relies on monitoring approach (experimental)	• Cleanup can be faster and more efficient • Able to intercept contaminated groundwater that is below the Tailings Area • Generally less risk, because it provides seepage and groundwater contaminant control from the start • Funding for the treatment component is secured at the outset as part of the overall mine closure budget • Treatment capital and operating cost is small compared to overall mine closure budget
Disadvantages	• May take several years for vegetation to be fully established and become functional • Does not treat seepage and groundwater from dams • If seepage and groundwater treatment becomes necessary in the future, additional funding may need to be acquired • Generally riskier because of the chance seepage may continue	• Greater capital costs • Greater O&M costs • Requires the use of pumps (not passive) • Disposal of used peat may be necessary after several years of operation. • Requires source of peat

Since the vegetated soil cover and seepage and groundwater treatment system require long-term commitments and secure funding, the selection of the appropriate approach requires further consideration by the MOE.

The main advantage of the alternative that includes pumping the seepage and groundwater to the wastewater treatment plant is that for a relatively low cost, cobalt discharge via seepage and groundwater flow will be controlled on an interim basis until the vegetation reaches its full evapotranspiration potential. The period it takes for the trees to reach that stage can be put to use to monitor seepage and groundwater flow rates to sumps located near the east and west tailings dams and to assess the effectiveness of the wastewater treatment plant for reducing cobalt loadings. Based on the data acquired over time, this will allow for determination of whether the construction of peat beds and constructed wetland systems are warranted after a period of about seven years. The disadvantage of this alternative is that, in the event that seepage and groundwater flow rates are found to remain relatively high once the poplar trees reach maturity, it may be necessary to construct the peat bed and wetland systems as a contingency measure. Construction may be at a higher cost than if they were built at the same time as the vegetated engineered soil cover.

6. Recommended Rehabilitation Alternative

In the previous sections, comprehensive remediation alternatives were developed, evaluation criteria were identified and the remediation alternatives were evaluated with respect to these criteria and site-specific conditions. The recommended alternative was based on reducing water contact and infiltration through the surface of the Tailings Area, treatment of seepage and groundwater during the vegetation establishment period and after, as required, and reducing the amount of surface run-on from the surrounding environment.

6.1 Key Components of the Recommended Alternative

The recommended alternative for meeting site closure objectives is to cover the surface of the existing crushed limestone cap with an engineered soil cover and vegetation (hybrid poplar trees are expected to provide the greatest benefit), collection and pumping of seepage and groundwater associated with the tailings impoundment for treatment, and through the construction of an interceptor ditch to divert surface runoff. For a period of four to seven years (period during which the hybrid poplars are expected to reach maturity), it is expected that the seepage and groundwater from the Tailings Area will be directed to the equalization pond located in the Industrial Area via a collection and pumping system for treatment. This is consistent with previous work (Geocon, 1986) that recognizes the compatibility of this approach to the surrounding environment, while effectively providing contaminant loading reduction to the Moira River and Young's Creek.

6.1.1 Site Preparation

Prior to commencing the remedial work, site preparation work will be completed that includes mobilization of equipment (excavators, trucks, site trailers and other equipment), construction of access roads and establishment of temporary services. Confirmation that heavy construction equipment can be supported on the tailings will need to be determined at the outset.

6.1.2 Construction of Engineered Soil Cover and Hybrid Poplar Trees Plantation

As described in Section 5.4.5, the preferred choice of soil cover consists of a layer of silty clay loam in combination with topsoil, sand, and compacted clay materials. A geotextile would separate the cover soils from the crushed limestone. The topsoil provides the initial rooting medium for the poplar trees, while the silty clay loam and sand provide the necessary water storage capacity that will increase the effectiveness of the poplar trees. The compacted clay layer functions as a restricting layer to minimize percolation of water into the underlying limestone cover and tailings (red mud). Based on the findings of the feasibility study (CH2M HILL, May 2002), the construction of a soil cover incorporating a 100- or 150-cm silty clay loam in addition to a 15-cm topsoil layer, a 30-cm sand drainage layer, and a 30-cm compacted clay base is predicted to be sufficient to achieve deep percolation reductions of

83 to 93 percent above existing conditions. Material availability and cost will determine the materials of construction and their quantities.

6.1.3 Construction of Interceptor Ditch System

Although the use of a soil and vegetation cover is predicted to be effective in reducing the infiltration and deep percolation of water, an interceptor ditch is recommended to achieve a greater level of water inflow reduction. The advantages of an interceptor ditch are a reduction of the water flow into the Tailings Area and an expected reduction of the influx of contaminants into the Moira River and Young's Creek.

An effective interceptor ditch could be constructed along the north and east side of the Tailings Area, where reduction in effective catchment area can be achieved. Surface water run-off would likely be diverted to Young's Creek.

6.1.4 Collection and Treatment

Installing a collection and pumping system between the Tailings Area and the equalization pond in the Industrial Area will allow for the movement of both seepage and groundwater from the Tailings Area to the equalization/storage basin for treatment at the onsite wastewater treatment plant. Provided that the existing wastewater treatment plant can satisfactorily remove dissolved cobalt from the effluent (the limited existing data suggests that it can), the increase in capital and operation and maintenance costs associated with the installation of a collection and pumping system is considered low compared to the load reduction potential of cobalt to the environment.

6.2 Operation and Maintenance Requirements

Operating, maintenance and monitoring efforts under the recommended alternative will be associated primarily with the Tailings Area cover maintenance (grass mowing in the first three years, tree replacement and culling, as required, downloading soil moisture data, vegetation sampling and analysis), seepage water collection and pumping system operations and maintenance, and seepage water quality and quantity monitoring. A detailed operations and maintenance plan should be established for the Tailings Area following implementation of the recommended alternative.

6.3 Cost Opinion

A breakdown of the estimated costs associated with the recommended alternative is provided in Appendix B and is summarized in Table 6.1. The costing in Appendix B has been completed at the conceptual design level and should be considered as a "cost opinion" to assist in selecting a preferred alternative. Costs can further be defined, once the preferred remediation alternative has been selected and a detailed design and approach is developed.

The net present value costs presented below are the sum of the capital cost and the net present value of the operation and maintenance costs. The annual operation and maintenance costs have been transformed to a net present value assuming an effective interest rate of 5 percent and a planning horizon of 20 years. The effective interest rate includes inflationary effects. It should be noted that operation and maintenance effort and

costs will be required beyond the 20 year horizon. The 20 year period was selected based on the assumption that it is a reasonable period for budgetary planning purposes.

As shown in Table 6.1, the estimated capital cost for the preferred alternative is $5,265,700 with annual operation and maintenance costs of $139,700 (net present value of $1,828,400), for a total of $7,094,100.

TABLE 6.1
ESTIMATED COSTS FOR IMPLEMENTING RECOMMENDED ALTERNATIVE

Cost Item	Estimated Cost
Capital Cost Items	-
1. Site Preparation	$113,300
2. Soil Cover	$4,197,500
3. Hybrid Poplar Tree Technology	$201,300
4. Surface Runoff Diversion	$184,900
5. Collection and Pumping to Equalization Pond	$111,000
6. Overhead, Insurance, and Bonds	$457,700
Total Capital Costs	**$5,265,700**
Operation and Maintenance Cost Items (Annual)	
1. Hybrid Poplars	$130,100
2. Collection and Treatment	$9,600
Total Annual O&M Costs	**$139,700**
Net Present Value O&M Costs	**$1,828,400**
Net Present Value of Capital and O&M Costs	**$7,094,100**

6.4 Data Gaps

The structural integrity of both the east and west tailings dams will need to be inspected as part of the closure plan development. This measure of assurance is needed to ensure that the tailings dams do not fail during construction or in the long-term due to excess pressures from the weight of added materials or due to the weight and action of the construction equipment. Based on the recommendations resulting from these inspections, additional work may be needed to reinforce the dams, due to the proposed placement of additional material on top of the tailings impoundment. Earlier investigations by Geocon (1986) indicate that both the east and west tailings dams are cracked and honeycombed due to the acidity of tailings pore water. Therefore, these structures would likely need to be reinforced to provide additional strength to reduce the risk of failure into adjacent water bodies. Costs associated with dam inspections and reinforcement, and the bearing capacity of the tailings for additional load from added cover materials and heavy equipment for placing the cover materials, are unknown at this time and have not been included in the cost estimates.

The enhancing environmental protection feature proposed herein to collect and pump seepage and groundwater from the Tailings Area to the equalization pond is based on an assumption that the existing wastewater treatment plant at the site can remove dissolved cobalt from the dam seepage water. Because the treatment plant was optimized for arsenic

removal, it will be necessary to undertake a monitoring program of the dissolved cobalt concentration present in the inlet and outlet of the wastewater treatment plant to determine whether the plant can effectively remove dissolved cobalt.

Confirmation of material availability and associated costs must be used in optimizing the design. This could include limiting the use of high-quality clay and the use of more low-cost materials, which may lead to a trade-off between the cost of reducing infiltration and the cost of treating the seepage and groundwater. Early indications are that the cost of treatment is lower than the cost of infiltration reduction. The approach will be optimized in the Tailings Area Closure Plan.

There is some potential to use the low-impacted silty clay material from Young's Creek as a source of soil for component parts of the Tailings Area cover. Further study is required to determine if this marginally contaminated material can be used without creating adverse impact. Should this material prove satisfactory, the costs of implementing the recommended remediation alternative will be less.

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APPENDIX A

MOE EA CRITERIA

TABLE A.1
RELATIONSHIP BETWEEN DETAILED EVALUATION CRITERIA AND ENVIRONMENTAL ASSESSMENT SCREENING CRITERIA

Environmental Assessment Screening Criteria	Detailed Evaluation Criteria									
	Social Considerations						Natural Environment			
	Public Acceptance	Risk to Public	Constraint for Recreational Use	Negative Impact to Private Properties	Visual Character of the Area	Risk to Workers	Geochemistry	Terrestrial Habitats	Floodplain	Fish Habitats
Affect air quality	x	x	x	x		x		x		
Affect water quality or quantity (ground or surface)									x	x
Affect species at risk or their habitat								x		x
Affect significant earth or life science features							x	x	x	x
Affect fish or other aquatic species, communities, or habitat									x	x
Include or use land subject to natural or human-made hazards										
Affect the recovery of a species under a special management program (e.g. elk restoration)										
Affect ecological integrity							x	x	x	x
Affect terrestrial wildlife or habitat, linkages or corridors (including movement of resident or migratory species)								x	x	
Affect natural vegetation and habitat through fragmentation								x	x	x
Affect permafrost										
Affect drainage, sedimentation or erosion									x	x
Release contaminants in soils, sediments	x	x	x	x		x	x			
Create excessive waste materials							x			
Affect areas of natural and scientific interest or provincially significant wetlands	x								x	x
Affect other (specify)										
Affect remoteness (access to inaccessible areas)										
Affect or obstruct navigation	x		x	x						
Affect other projects within a park or reserve										

TABLE A.1
RELATIONSHIP BETWEEN DETAILED EVALUATION CRITERIA AND ENVIRONMENTAL ASSESSMENT SCREENING CRITERIA

Environmental Assessment Screening Criteria	Detailed Evaluation Criteria									
	Social Considerations						Natural Environment			
	Public Acceptance	Risk to Public	Constraint for Recreational Use	Negative Impact to Private Properties	Visual Character of the Area	Risk to Workers	Geochemistry	Terrestrial Habitats	Floodplain	Fish Habitats
Affect other projects outside a park or reserve	x	x	x	x	x					
Affect traffic patterns	x		x							
Affect public or private recreation	x		x				x	x		
Commit a significant amount of a non-renewable resource (e.g. aggregates)								x		
Affect noise levels	x	x		x		x				
Affect views or aesthetics					x			x	x	
Be a precondition or justification for implementing another project										
Affect uses, persons or property outside park or reserve	x	x	x	x	x	x	x			
Affect other (specify)										
Affect cultural heritage or landscape features		x		x	x					
Displace people, businesses, institutions, or public facilities				x						
Affect community character, enjoyment of property, or local amenities	x		x	x				x	x	
Increase demands on government services or infrastructure										
Affect public health and/or safety		x				x			x	
Affect local economies				x						
Affect local businesses				x						
Affect other (specify)										
Affect First Nation reserves or communities										
Affect spiritual, ceremonial or cultural sites										
Affect traditional land or resource uses, or affect economic activities										
Affect Aboriginal values										
Affect other (specify)										

APPENDIX B

DETAILED COST OPINION

APPENDIX B

Opinions of Probable Construction Cost

In providing opinions of probable cost, MOE understands that CH2M HILL has no control over the cost or availability of labour, equipment or materials, or over market conditions or the potential Contractor's method of pricing. CH2M HILL makes no warranty, express or implied, that the bids or the negotiated cost of the Work will not vary from the opinion of probable construction cost.

CH2M HILL has made efforts to acquire area specific rates for materials, labour, and equipment whenever possible. The suitability of said materials to the intended purposes were not verified and will need to be determined prior to any construction activities. Where a local source or supplier could not be identified, industry budgetary tools such as the R.S. Means Company Inc. costing guide were used to assign a typical value. Appropriate regional coefficients were applied where necessary to adjust the typical costs to address regional conditions.

Each specific area of interest has been examined as an independent project. Any possible synergies associated with co-execution of various areas were ignored. Prices provided include the federal Goods and Services Tax (GST).

Volumes and areas were determined using existing available information. No additional investigations were performed to confirm or refute the estimates. Some estimates such as potential water volumes were based on engineering experience from other similar projects. Probable construction costs were based on typical weather conditions and may require adjustments due to extreme conditions.

Certain construction costs such as overhead, insurance, and various construction bonds will vary based on the potential Contractor. Financial strength, experience, and previous history all play a role in determining the rates that will be applied to a particular Contractor. These sums were determined as a percentage of the total costs based on industry averages.

Several of the options involve additional pumping to the arsenic treatment plant located in the Industrial Area. The application of a varied number of options over the four main areas will result in increases and decreases of the total treated water volume. At this conceptual stage it is difficult to determine whether there will be a net increase or decrease to the volume of water to be treated. Therefore, the operation and maintenance of the arsenic treatment plant has only been considered in the Industrial Area evaluation. Actual operation and maintenance costs over the last decade were used to develop a weighted-average and one standard deviation was added to this value in an effort to create a conservative estimate. Wastewater treatment considerations for all other areas were limited to collection and transmission to the equalization pond (i.e. equalization/storage basin).

The annual operation and maintenance costs have been transformed to a net present value assuming an effective interest rate of five percent and a planning horizon of 20 years. The effective interest rate includes inflationary effects. The 20-year planning period was selected based on the assumption that it is a reasonable period for budgetary planning purposes.

Finally, a 15% contingency was added to the final cost before taxes, overhead, insurance, and bonds.

Breakdown of Major Cost Items
For the Comprehensive Remediation Alternatives

	Alternative 1 Soil Cover and Vegetation	*Alternative 2 Soil Cover and Vegetation Diversion of Surface Runoff*	*Alternative 3 Soil Cover and Vegetation Collection and Treatment (Natural Treatment System)*	*Alternative 4 Soil Cover and Vegetation Collection and Treatment (Wastewater Treatment Plant)*	*Alternative 5 Soil Cover and Vegetation Diversion of Surface Runoff Collection and Treatment (Natural Treatment System)*	*Alternative 6 Soil Cover and Vegetation Diversion of Surface Runoff Collection and Treatment (Wastewater Treatment Plant)*
A. Capital Costs						
Site Preparation	$113,300	$113,300	$113,300	$113,300	$113,300	$113,300
Soil Cover	$4,197,500	$4,197,500	$4,197,500	$4,197,500	$4,197,500	$4,197,500
Hybrid Poplar Technology	$201,300	$201,300	$201,300	$201,300	$201,300	$201,300
Diversion of Surface Runoff (enhancement)	NA	$184,900	NA	NA	$184,900	$184,900
East Wetland	NA	NA	$252,500	NA	$252,500	NA
West Wetland	NA	NA	$563,200	NA	$563,200	NA
Collection and Treatment (at existing wastewater treatment plant)	NA	NA	NA	$111,000	NA	$111,000
Subtotal	$4,512,100	$4,697,000	$5,327,800	$4,623,100	$5,512,700	$4,808,000
Overhead, Insurance and Bonds	$429,600	$447,200	$507,200	$440,100	$524,800	$457,700
Total (Including Enhancements)	**$4,941,700**	**$5,144,200**	**$5,835,000**	**$5,063,200**	**$6,037,500**	**$5,265,700**
Total (Excluding Enhancements)	**N/A**	**$4, 959,300**	**N/A**	**N/A**	**$5,852,600**	**$5,080,800**
B. Annual Operation and Maintenance Costs						
Hybrid Poplars	$130,100	$130,100	$130,100	$130,100	$130,100	$130,100
East and West Wetlands	NA	NA	$112,000	NA	$112,000	NA
Collection and Treatment	NA	NA	NA	$9,600	NA	$9,600
Total	$130,100	$130,100	$242,100	$139,700	$242,100	$139,700
Net Present Value of Annual O&M Costs	**$1,702,600**	**$1,702,600**	**$3,168,400**	**$1,828,400**	**$3,168,400**	**$1,828,400**
C. Net Present Value Capital and O&M Costs						
NPV of Capital and O&M Costs (Incl. Enhancements)	**$6,644,300**	**$6,846,800**	**$9,003,400**	**$6,891,600**	**$9,205,900**	**$7,094,100**
NPV of Capital and O&M Costs (Excl. Enhancements)	**N/A**	**$6,661,900**	**N/A**	**N/A**	**$9,021,000**	**$6,909,200**

Note: All costs include GST and a 15% contingency (before taxes, overhead, insurance, and bonds)